FAULT DETECTION AND ISOLOATION IN LOW-VOLTAGE DC-BUS MICROGRID SYSTEMS

by

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ABSTRACT

Unlike traditional AC distribution systems, protection has been challenging for DC systems. Multi-terminal DC power systems do not have the years of practical experience and standards that AC power systems have. Also, the current power electronic devices can not survive or sustain high magnitude faults. Conveters will shut down to protect themselves under faulted conditions. This makes locating faults in DC system difficult, and causes the DC bus to de-energize. A fault protection algoritm and method for a low-voltage DC-bus microgrid system is presented in this thesis in order to revolve the above issues. The main goal of the protection method is to detect and isolate faults in the DC system without degenergizing the entire DC bus. In order to achieve this a ring bus was utilized for the main DC bus. The bus was then segmented into individual zones with solid state bi-directioanl switches used to isolate the zone in the event of a fault. Each zone is monitored and controlled by an individual Intellegent Electrical Device. A grounding resistor was added in order to limit the amount of ground current. The concepts have been verified in OrCAD/Psice and MATLAB.

This abstract accurately represents the content of the candidate's thesis. I recommend its publication.

Jae-Do Park,Ph.D

DEDICATION

This thesis is dedicated to my two young daughters, Madilynn and Kennedy. I hope that this can serve as an example the value of importance of an education.

ACKNOWLEDGMENT

I would like to first thank my wife for allowing me the time to attended my graduate classes and conduct research while she took care of our children. I would like to thank my grandparents for supporting me in pursuing this degree and helping watch my children so that I could do so. I would like to acknowledge Dr. Keith Malmedal for sparking my interest in power systems and hirig me for my first job in power systems. Without that first job I would not be where I am today. Lastly, I would like to thank Dr. Jaedo Park for his encouragemnet and support during my time at the University of Colorado Denver. Without him this thesis would not have been possible.

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1. Introduction

At the end of the 19^{th} century the war to electrify the world was waged. On one side sat Thomas Edison with his DC system and on the other was George Westinghouse and Nikola Tesla with their AC system. In the beginning Edison was winning with the opening of the Pearl Street Station in New York, 1882 [39]. Unfortunately for Edison the technology to increase a DC voltage to transmission level was not yet available. AC systems had the ability to reach such voltages with the technology of the time. In 1893 Westinghouse and Tesla successfully supplied 11MW of electricity to the Chicago World's Fair. Then in 1895 the Adams Hydroelectric Generating Plant (Fig.1.1) was opened at Niagara Falls, serving local utilities in Niagara Falls. By 1910 transmission lines were serving loads in Southern Ontartio[40]. This marked the birthplace of AC power and set in motion it's dominance in the world.

Even though AC clearly won the war, research and development into DC did not stop. In the 1920's mercury arc valves became available for use in power transmission. In the 1950's high power transistors like the thyristor were introduced allowing higher voltage and power ratings [11, 5]. These inventions led to the use of High Voltage Direct Current (HVDC) Transmission, to transmit power over great distance. HVDC has also been used as an asynchronous ties between separate power grids. These systems using thyristor valves are commonly referred to as Classical or Line Commutated Converter (LCC) HDVC have been in place since the 1970's, and have been a vital part of the modern

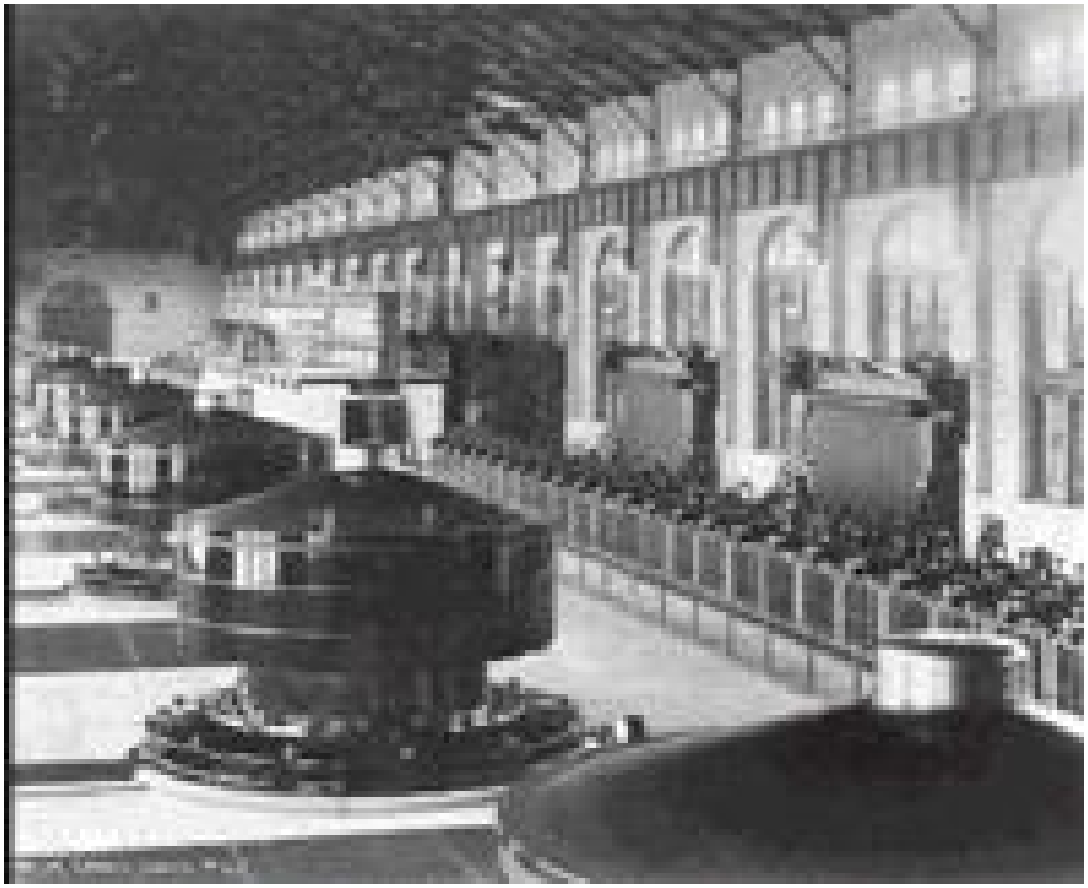

Figure 1.1: Adams Hydroelectric 3 Phase AC Generating Plant.

grid.

Recently many distributed power systems have been researched and developed, especially to meet the need for high penetration of renewable energy resources such as wind turbines and photovoltaic systems. The distributed power systems have advantages such as the capacity relief of transmission and distribution, better operational and economical generation efficiency, improved reliability, eco-friendliness and power quality [19, 14, 9]. The current energy policy of many governments in the world is to competitively increase the requirement of the penetration of renewable energy sources and distributed generation. For instance, California is trying to increase the usage of renewable generation up to 33% by 2020 [54] and the State of Colorado has set specific requirements for distributed generation from eligible renewable energy resources [55].

The microgrid system is a small-scale distributed power system consists of distributed energy sources and loads, and it can be readily integrated with the renewable energy sources [33, 42, 29, 41, 46, 25]. Due to the distributed nature of microgrid approach, the connection to the central dispatch can be removed or minimized and in turn the power quality to sensitive loads can be enhanced. Most microgrid systems have their connected distributed energy sources interfaced through power electronics converters. Generally they have two operation modes: standalone (islanded) and grid-connected operation.

Microgrid systems can be divided into AC-bus and DC-bus systems, based on the bus that the component systems such as energy sources, loads and storages are connected to. AC-bus based microgrids are advantageous because the existing AC power grid technologies can be readily applicable. Currently, all of the commercially installed microgrids are AC [7]. DC microgrids have several advantageous over AC which will be coved in this thesis. One of the main reasons that DC microgrids are not as prevalent as AC microgrids is that the system protection is in it's infancy. The protection of DC systems is not standardized and often requires a complete shutdown of the DC bus[15, 53, 52].

This thesis presents a fault protection method and algorithm for a low-voltage DC-bus microgrid. The primary goal of the proposed method is to detect the fault in a bus segment between devices and isolated the faulted section so that the system keeps operating without disabling the entire system. This thesis will provide a comparison of AC and DC systems, present the types of DC systems available, and give an overview of the current DC protection methods. Finally, the protection method and algorithm will be provided with simulation results.

2. Microgrid Systems

2.1 AC vs. DC

Microgrid systems can be divided into AC-bus and DC-bus systems, based on the bus that the component systems such as energy sources, loads and storages are connected to. AC-bus based microgrids are advantageous because the existing AC power grid technologies can be readily applicable. However, AC grid issues including synchronization, reactive power control, and bus stability are inherited as well. DC-bus based systems can become a feasible solution because microgrids are small, localized system that the transmission loss is negligible, unlike the traditional power systems that have a long line of transmission and distribution. Moreover, it does not need to consider the AC system issues and system cost and size can be reduced compared to the typical AC-DC-AC conversion configuration because DC power is generally used in the power electronics devices as a medium. A conceptual diagram of DC-bus microgrid is shown in Fig. 2.1.

While the advantageous of DC microgrids are great, protection of DC distribution systems has posed many challenges such as autonomously locating a fault within a microgrid, effectively breaking a DC arc, DC protection devices, and certainly the lack of standards, guidelines and experience [47, 15].

2.2 HVDC vs. LVDC

When it comes to power transmission systems HVDC is the most prominent. HVDC lines have been a part of the United States grid for over 40 years. HVDC

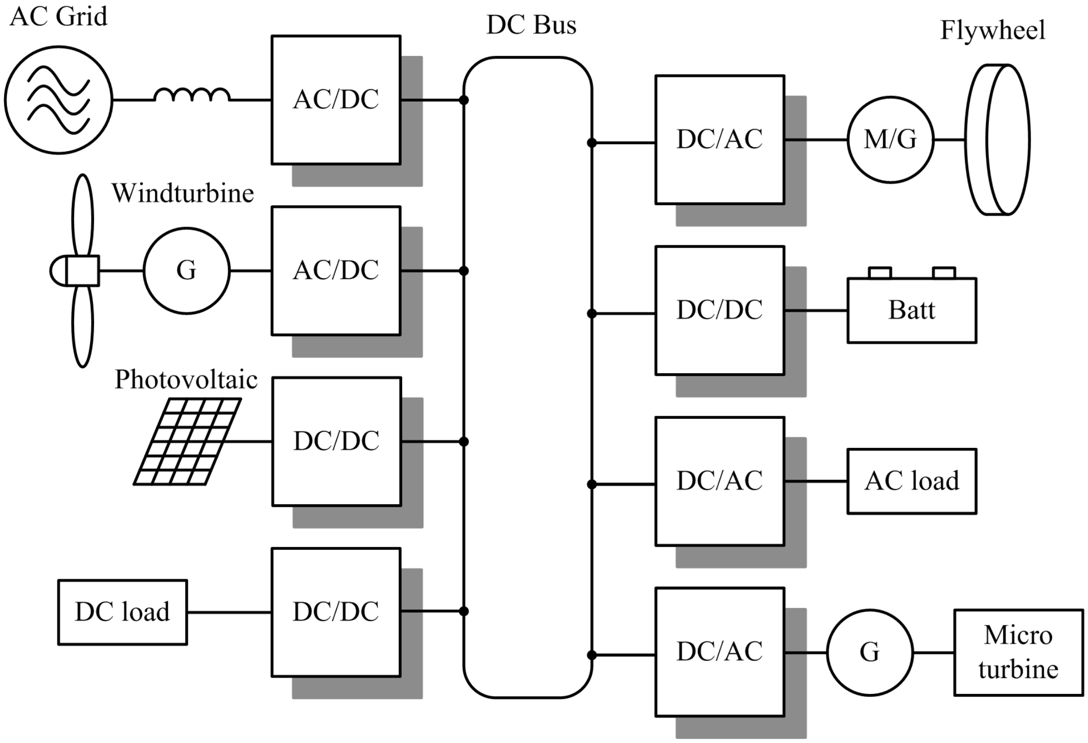

Figure 2.1: Conceptual diagram of a DC-bus microgrid system.

lines help transmit bulk power overlong distances and interconnecting the three grids in the in the United States. In traditional power systems there are three main components: generation, transmission and loads. Generally the generation is a large power plant (coal, nuclear, etc.) and is located outside large cities, while most of the loads lie within these large cities. The transmission component delivers energy from the generation sites to the loads. This is how the power systems around the world currently work. Thus the reason for the dominance of HVDC over LVDC.

Attitudes and views on how the power system should operate have begin to shift and decentralization of the grid is beginning to gain attention. This would mean that traditional loads would install local generation often called independent power producers (IPP). The local generation can be used to supply the local loads, thus decreasing the transmission losses. When the IPP produces more electricity than the load consumes it can sell the power back to the utility, and when production falls short the grid is there to make up the difference. It is in this application that LVDC has started to gain attention. Although, the electric grid is primarily AC many of the loads in our homes and businesses are DC. This means that each of these devices requires a small AC-to-DC converter, which increases losses. If local IPP's produce DC power that the loads are able to use directly it would decrease these conversion losses. This is especially advantageous for data centers where almost all of the equipment is DC. Recently, the European Telecommunications Standards Institute (ETSI) began drafting a standard on 380VDC wiring for building-wide power distribution [43].

2.3 LCC vs. VSC

Currently line commutated converters (LCC) or classical thyristor-based DC systems hold the market in bulk power transmission. Recently voltage source converter based DC systems are becoming more of a competitor of classical thyristor-based DC systems [21]. Not only is VSC a competitor for transmission but it can also be used in multi-terminal systems, which have become an attractive option for renewable energy applications or for distribution in large cities. As the converter power rating increases it may one day replace thyristor-based converters. VSC's are attractive because, unlike classical converters, no reactive power support is needed to operate the system. In fact VSC's can produce reactive power, and control active and reactive power independently [3]. This controllability allows VSC converters to operate in systems with little or no AC support, something that classical converts cannot achieve without expensive support [13, 17, 48, 22]. VSC's are also advantageous in multi-terminal systems. Multi-terminal systems consist of three or more converters to create a DC network. Applications of multi-terminal systems include distribution into large cities, microgrids, and even ship power systems [52, 20, 53, 6]. VSC's are better suited for multi-terminal systems as the power flow can be changed by changing the direction of the current. Classical DC converters require the DC voltage polarity to be changed, which can be difficult [35, 44, 13].

VSC systems are, by design, vulnerable to faults on the DC systems. Classical HVDC systems are naturally able to withstand short circuit currents

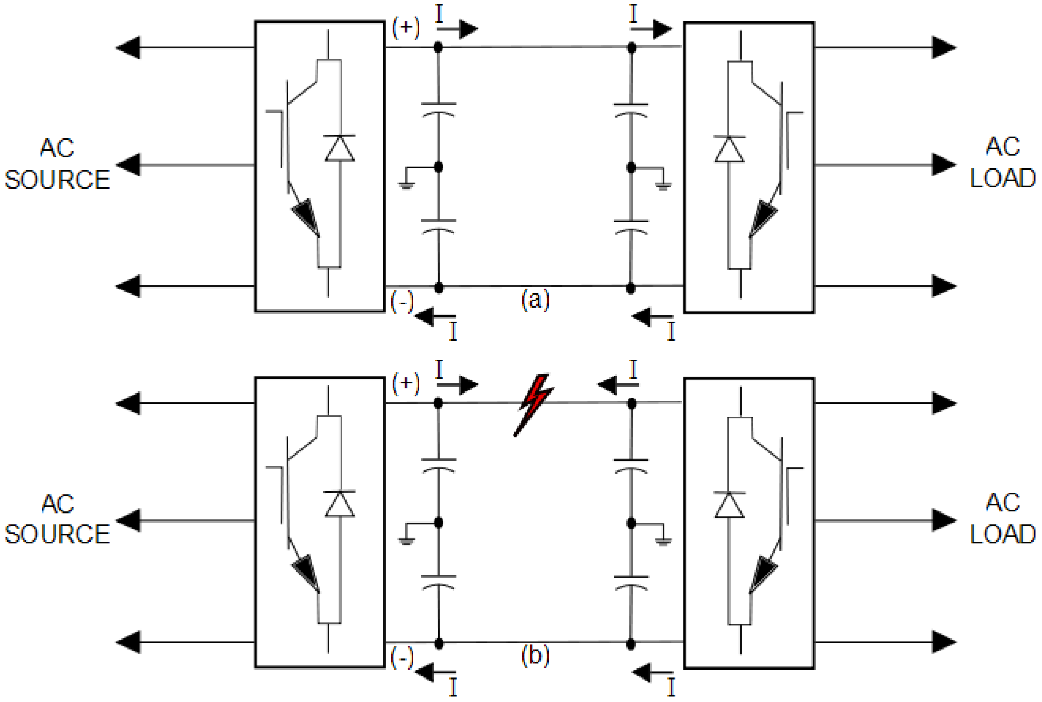

Figure 2.2: VSC Operation (a) Normal. (b) Positive Line-to-Ground Fault.

due the DC inductors limiting the current during fault conditions [20, 56]. When a fault occurs on the DC side of a VSC system the IGBT's lose control and the freewheeling diodes act as a bridge rectifier and feed the fault [52, 34, 23, 53, 57, 6, 56, 18], as shown in Fig. 2.2. The types of faults possible on a HVDC system are as follows.

A challenge associated with the protection of VSC systems is that the fault current must be detected and extinguished very quickly as the converters fault withstand rating is generally only twice the converter full load rating [6]. Fault detection is also important, especially on multi-terminal systems, in order to isolate the fault and restore the system to working order.

3. Fault Protection of Low-Voltage DC-bus Microgrid Systems

3.1 Possible Faults

For DC system two types of faults exist, line-to-line and line-to-ground,as can be seen in Fig. 3.1. A line-to-line fault occurs when a path between the positive and negative line is created, shorting the two together. A line-to-ground fault occurs when a path between either the positive or negative pole and ground is created. A line-to-ground fault is the most common type of fault[10].

VSCs may experience internal switch faults that can cause line to line short fault. This is a terminal fault for device that can't be cleared and in most cases it requires replacement of the device. Hence, DC fuse would be proper protection measure for

3.1.1 Line to Ground

A line-to-ground fault (ground fault) occurs when the positive or negative line is shorted to ground. In overhead lines faults may occur when lightning strikes the line. This may cause the line to break, fall to the ground and create fault. In this situation the fault is always permanent and the line must be isolated for repair. Ground faults may also occur by objects falling onto the line, such as trees, providing a path to ground. In some cases when an object causes the ground fault it may fall away from the line and the system can be restored. If the fault persists the line would have to be taken out of service until the fault path can be cleared.

Underground cable is almost completely immune to line-to-line faults, as insulation, conduit and the earth separate the cables. However, they can still occur. The insulation of the cable can fail due to improper installation, excessive voltage/current, exposure to the environment(water, soil, etc) or cable aging [56]. When this occurs, the broken insulation will allow a path for current to flow to ground. As the fault persists the integrity of the insulation is reduced causing the fault to worsen. A ground fault may also occur when a person inadvertently cuts through one of the lines. This generally happens during construction projects. In either case the fault will always be permanent and will require a complete shutdown of the line as well as a costly repair.

When a line-to-ground fault occurs, the faulted pole rapidly discharges capacitor to ground. This causes an imbalance of the DC link voltage between the positive and negative poles. As the voltage of the faulted line begins to fall, high currents flow from the capacitor as well as the AC grid. These high currents may damage the capacitors and the converter [57].

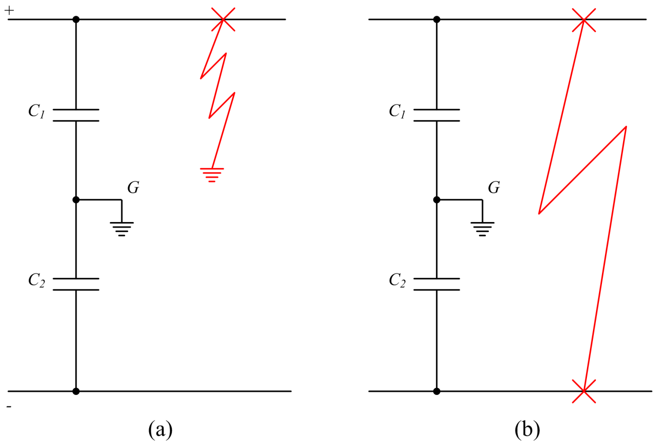

Figure 3.1: a) Line-to-Ground Fault b) Line-to-Line Fault

3.1.2 Line to Line

As stated before, a line-to-line fault on a cable-connected system is less likely to occur on the cable. In an overhead system, line-to-line faults can be caused by an object falling across the positive and negative line, they may also occur in the event of the failure of a switching device causing the lines to short. A switching fault, which is independent of how the converter stations are connected together, causes the positive bus to short to the negative bus inside the converter. A line-to-line fault may be either temporary or permanent.

3.1.3 Overcurrent

While overcurrent protection is important during line-to-line and line-to-ground faults, it must also operate when the system is being overloaded. Overload conditions may occur in two-terminal systems when the load increases past the rating of the converter or as a result of a fault on another part of the system. For example, if three VSC's are feeding a common load and one VSC is dropped due to a permanent fault, the remaining two must supply the load. This will result in elevated currents that may overload the converters. In this situation the overcurrent protection would need to operate. Another option to avoid a wide spread blackout would be to shed non-critical loads.

3.2 Current Protection Methods

Although, a standard has not been agreed upon on how to best protect DC systems, many methods have been proposed. Most of these methods are proposed for high voltage direct current (HVDC). This is because more HVDC systems have made it to consumer production, and therefore has been a popular research topic. However, the concepts and ideas are the same for LVDC systems. The below sections will overview these proposed methods.

3.2.1 DC Protection with AC Devices

Traditionally protection of DC systems has been done with conventional AC devices such as circuit breakers and fuses. The advantages of using AC devices include:

- Less expensive than DC counterparts
- Shorter lead time
- Mature science
- More familiar devices

The two options when choosing an AC device is either a circuit breaker or a fuse.

3.2.1.1 AC Circuit Breakers

Placing AC circuit breakers on the AC side of the VSC is the most economical way to protect the DC system. They are commonly available and can be replaced in a shorter amount of time. However, AC circuit breakers result in the longest interruption time as a result of their mechanical restrictions [52]. Currently, the best interrupting time for an AC circuit breaker is two cycles [2].

When using an AC circuit breaker, the voltage of the DC capacitors will be monitored as well as the current in each DC line at each converter. These values will be fed back to a standard relay, which will monitor over/undervoltage, as well as overcurrent. When a DC fault occurs, the capacitors will discharge rapidly causing the voltage to decrease. The current on the faulted line will increase over the rated value. Once the relay senses one or more of these conditions, it will trip the breaker. In an attempt to restore the system, the relay will enter a re-closing cycle in which the relay will close back in and sense the voltage and current of the DC system. If the fault is cleared the system will return to normal, but if a permanent fault is detected the relay will lock out the breaker. The relay identifies a permanent fault by the re-closing sequence. A typical industry standard for re-closing on AC systems is that two attempts will be made; this can be applied to the VSC systems as well. After two attempts without success, the relay determines that the fault is permanent and will not allow the breaker to close.

In back-to-back or two-terminal transmission systems, differential protection may be used to protect each converter, as shown in Fig. 3.2. The differential relay (Note: 87 is the ANSI standard number for a differential relay) will measure the current entering the converter as well as the current leaving the converter. If the current entering does not match the current leaving the differential relay, it will trip the AC breaker [4, 30]. In back-to-back systems one relay could also monitor the AC current at the sending VSC as well as the receiving VSC. If the current at one end does not match the current at the other end, the relay would know a fault has occurred and the VSC's would be tripped offline. In a two terminal transmission system, two relays would be required and the current readings would have to be sent to the other relay via communication as can be seen in Fig. 3.3. This type of differential protection is common in AC systems[10] as could be applied to VSC protection. Also, compensation for losses would have to be taken into account.

While AC circuit breakers are inexpensive, easy to use, and widely used, they also shut down the entire converter. This is problematic in the case of ground faults where the faulted line could be isolated and the system could run mono-polar using ground as a return path[57]. AC circuit breakers are also inconvenient in multi-terminal systems, which will be discussed later.

3.2.1.2 Fuses

Fuses on the AC side are generally not a good solution for protection of the VSC [38]. This is because a fuse is a thermal device that is only allowed one operation. Fuses do not have the ability to distinguish whether a fault is temporary or permanent. To a fuse every fault is permanent and therefore the system would not be able to be restored until the fuse was physically replaced. The only place that a fuse may be an acceptable alternative is for a non-critical load, or in areas where space is limited, such as a ship. Fuses are used for

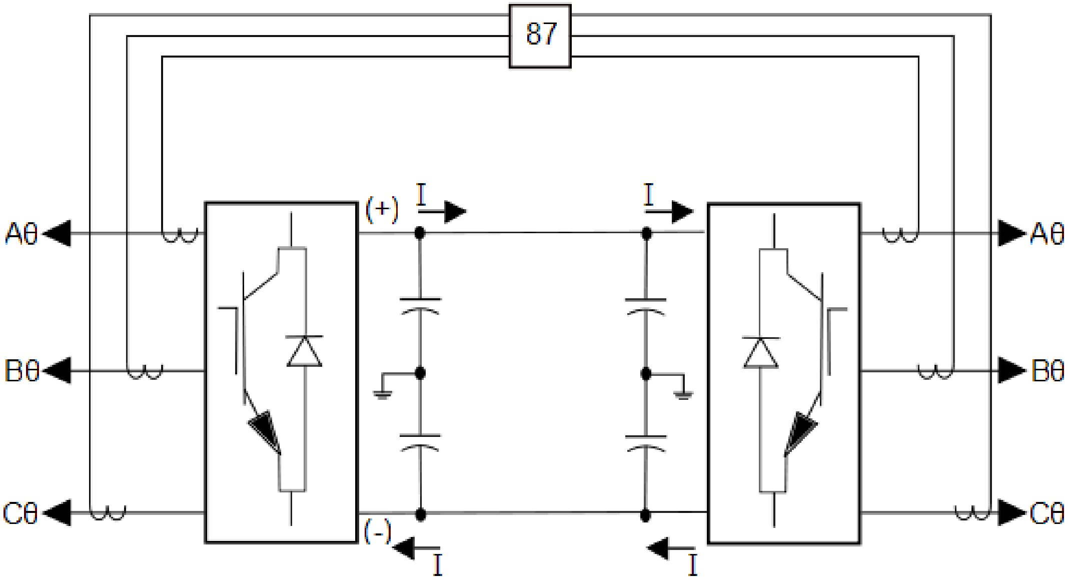

Figure 3.2: Back to Back Differential Protection.

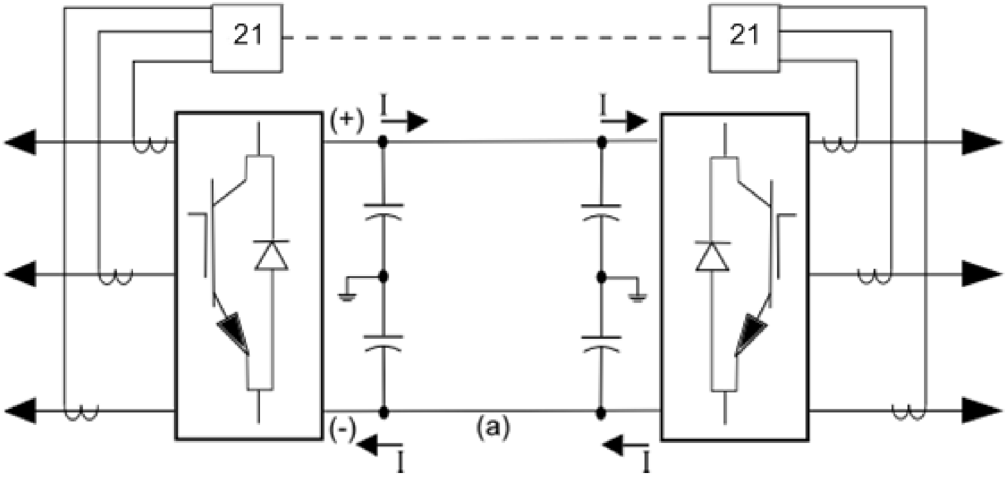

Figure 3.3: Two-Terminal Differential Protection

protection [38], but are mainly for AC protection and other DC devices protect the DC line. The DC devices coordinate with the fuse such that they will trip before the fuse. The fuse will only operate in the event that the DC protection fails. Overall, fuses should be used only when necessary and all other options are not possible.

3.2.2 DC Protection with DC Devices

While AC devices are an economical way to protect the DC system, DC devices are a better option whenever possible. DC protective devices can act faster than their AC counterparts, as well as sectionalize lines. This allows the operation of unfaulted lines to continue. The methods of protection using DC devices are shown below.

3.2.2.1 IGBT Circuit Breakers

An IGBT circuit breaker (IGBT-CB) utilizes the blocking capability of the solid-state device. Like the other IGBTs in the converters, the IGBT-CBs are configured with an anti-parallel diode. The only drawback to the IGBT-CB is that it is a uni-directional device. This is illustrated in Fig. 3.4. When a fault occurs on the DC line, the IGBT is able to block the fault current (represented by the dashed line in Fig. 3.4). If the fault occurs on the converter side, the anti-parallel diodes conduct and allow current to flow (represented by the solid line in Fig. 3.4). In this scenario the IGBT-CB must rely on the blocking of the IGBTs in the converter [52].

For two-terminal systems, IGBT-CBs can be placed at each converter station, one on the positive line and one on the negative line, as can be seen in Fig. 3.4. Fast acting DC switches are used in conjunction with the IGBT-CB, which is used to isolate the line once the fault current has been cleared. It should be noted that the switch cannot break current and may only be opened once the fault has been extinguished. As with AC, the DC current of each line and the DC voltage of each capacitor will be sensed. Once the control system senses a fault on the line, an appropriate IGBT-CB will receive a gate signal to block the current. Once the fault current has been extinguished the fast acting DC switches will open, isolating the line. To determine if the fault is temporary or permanent, the DC switches and the IGBT-CB will close. If the fault has cleared the system will return to normal operation. If the fault is still present, the line will be isolated again and a permanent fault will be determined.

The advantage of using an IGBT-CB is that the entire converter is not shutdown in the case of a ground fault. This allows the faulted line to be isolated and have the system continue to run mono-polar. The IGBT-CB also opens faster than its AC counterpart. The disadvantage to the IGBT-CB is that it cannot protect against DC rail faults in the rectifier [38].

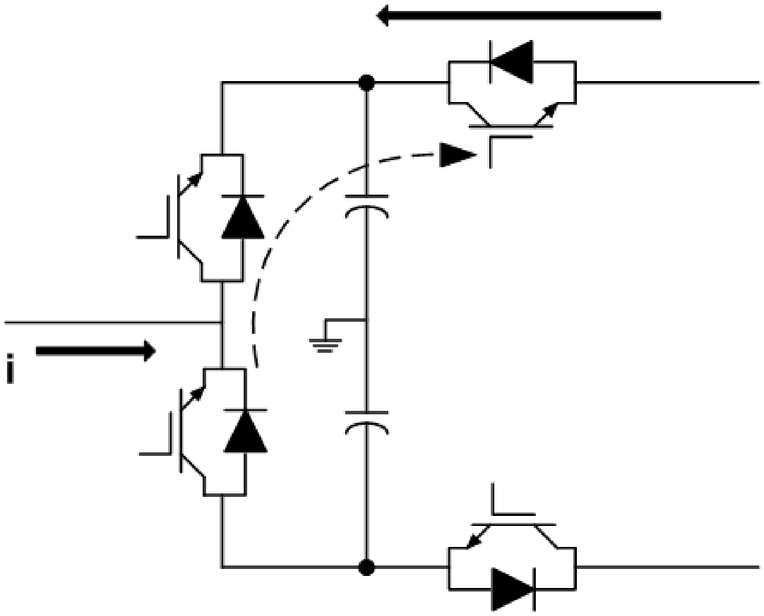

Figure 3.4: IGBT-CB Fault Blocking Capabilities.

3.2.2.2 Converter Embedded Devices

Converter embedded devices are active, protective components that are installed inside a VSC to detect and isolate DC faults. This method eliminates the use of additional devices, reducing the footprint of the converter station and also possibly cutting cost. However, a redesign of the converter is required. In [6], the converter uses two Emitter Turn Off (ETO) devices in an anti-parallel configuration to achieve both switching and protection. The ETO has a higher voltage and current rating than IGBT. Fig. 3.5 illustrates the converter configuration. In normal operation the ETO's X act as the switching devices, while ETO's Y act as the anti-parallel diode, and are constantly fired on. In the event of a fault the ETO's X are blocked while ETO's Y continue to feed the fault. Once the fault has been identified as permanent the Y ETO's will be gated off.

Another protection method has replaced the typical IGBT and anti-parallel diode is a combination switching device with the submodule shown in Fig. 3.6 [18, 22]. The converter submodule provides two different levels of protection. The first level protects the converter from being shutdown during a switching device failure. In the event of a switching device failure, the submodule will close switch K_1, shorting out the defective submodule. This allows the converter to continue to operate by using redundant modules for un-altered system performance. The second level of protection reacts under fault conditions. As stated earlier, the switching device blocks and the anti-parallel diode conducts to feed the fault under fault conditions. The freewheeling diodes in VSC's are not able to withstand large surge currents, and may be damaged before the fault is cleared. The solution in [18] is to bypass the IGBT and the anti-parallel diode with a press-pack thyristor K_2. The proposed press-pack thyristor is able to withstand high surge currents, protecting the anti-parallel diode until the fault can be cleared.

This protection method allows the converter additional control and increases the current rating of the switching devices. It also cuts down on the number of components required for protection because the protection is embedded in the converter. The disadvantage is that the entire converter must be shut down in the event of a permanent fault. This works well in two-terminal systems but may cause problems in multi-terminal systems.

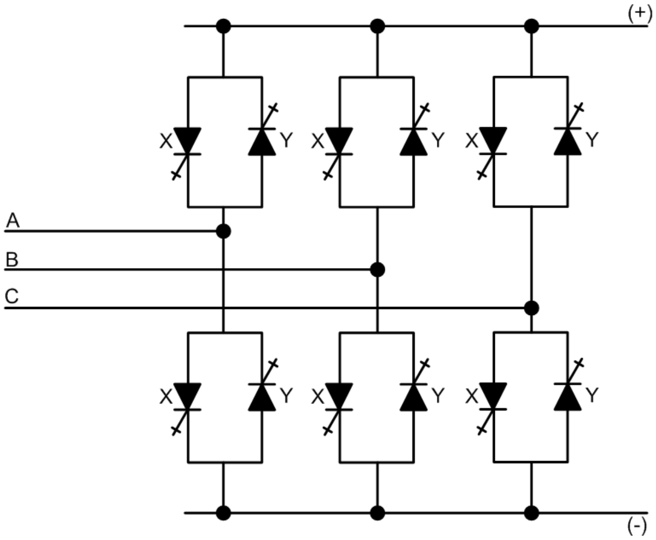

Figure 3.5: ETO Based VSC-HVDC Converter.

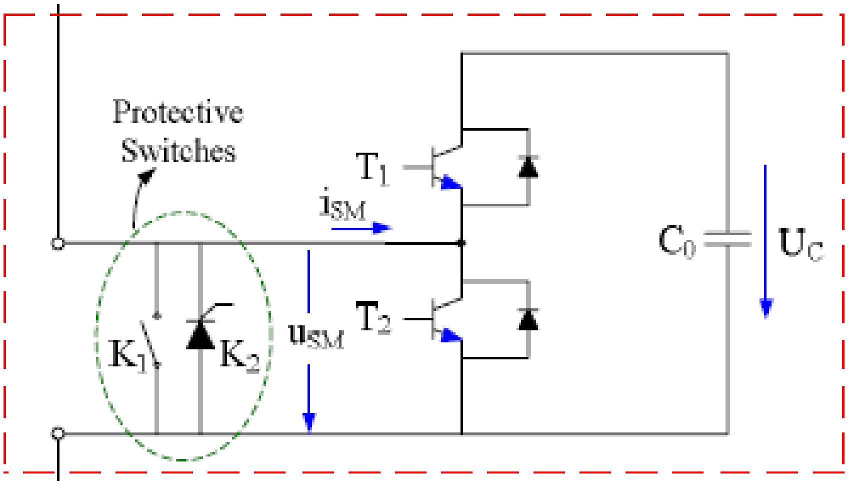

Figure 3.6: VSC-HVDC Converter Submodule.

3.2.3 Multi-Terminal System Protection

VSC systems are very appealing in multi-terminal systems, as power flow can be changed not by voltage polarity but the direction of the current. The possible applications for multi-terminal VSC (MT-VSC) systems are used in renewable energy applications and in distribution of power in mega cities. The protection strategies for MT-VSC utilize both AC and DC protection.

3.2.3.1 AC Protection

As stated previously, DC protection can be achieved by using AC circuit breakers on the AC systems. This strategy can be applied to MT-VSC as well. A "hand shaking" method is proposed in [53]. This method, in addition to using AC circuit breakers, implements fast acting DC switches. The switches are only used to isolate lines and cannot break load or fault current. Each VSC will receive current measurements from their respective DC switches. When a fault occurs all of the AC circuit breakers associated with the MT-VSC system will trip. Next, each VSC must determine which one of its respective switches to open. This is done by measuring the magnitude and direction of the current through each switch. The switch that will be selected is the one with the largest positive fault current. The hand shaking method defines positive as out of the node and negative into the node. Fig. 3.7 illustrates the example system given in [53].

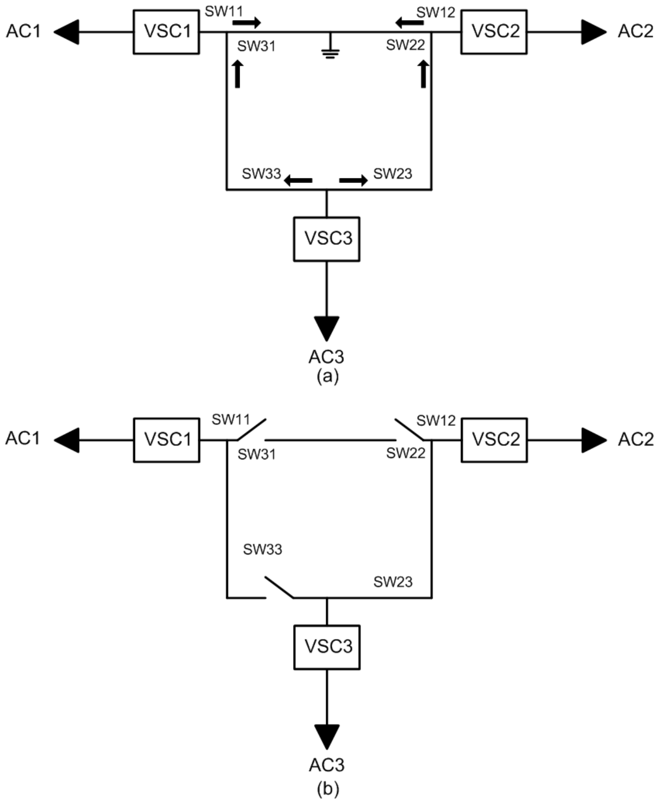

Figure 3.7: Hand-Shaking Method:(a) Current Flow During a Fault. (b) Fault Isolation.

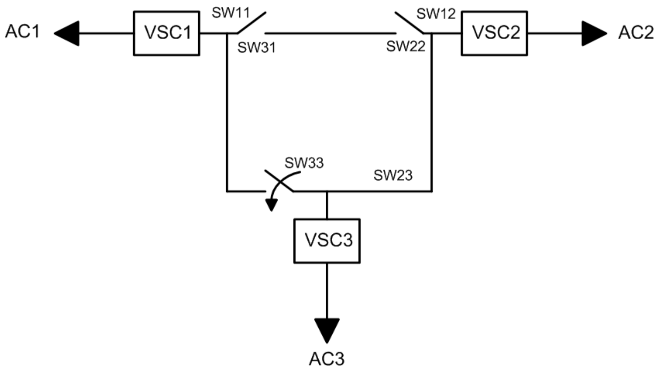

Figure 3.8: Hand Shaking Method Re-Closing.

When a fault occurs on Line 1, VSC1 receives current measurements from SW11 and SW31. VSC1 senses that the current through SW11 is positive and the current through SW31 is negative. Through the hand shaking method VSC1 opens SW11. VSC2 receives current measurements from SW12 and SW22. Once again the current through SW12 is positive and the current through SW22 is negative and switch SW12 is selected. VSC3 receives current measurement from SW33 and SW23. The current direction for both switches is measured as positive. The switch with the highest magnitude of current is selected. At this point Line 1, the faulted line, is isolated, and Line 3 is open at one end. At this point the system must enter a re-closing mode. First, all of the AC breakers will close back in, re-energizing the VSC's. Next, the fast DC switches of the non-faulted DC lines must be closed. The VSC's only re-close switches when the voltage of its respective line is near the voltage of the VSC terminals. Fig. 3.8 shows the re-closing method presented in [53], where it can be seen that only SW33 will be able to re-close. During the fault VSC1 chose to open SW11, leaving SW31 closed. Once the AC breakers re-close, and the VSC1 is back on line, Line 3 will recharge. VSC3 will sense the Line 3 voltage and allow SW33 to close. Both SW11 and SW12 will remain open as Line 1 was discharged during the fault and both VSC1 and VSC2 will sense no voltage on Line 1, therefore not allowing the switches to close.

3.2.3.2 DC Protection

DC Protection utilizes IGBT-CB's and fast acting DC switches. The IGBT-CB's can be placed at the terminals of each VSC or at the end of each line, as show in Fig. 3.9.

The voltage of the capacitors will be monitored as well as the current through each line. When the current exceeds the maximum setpoint and the voltage begins to rapidly discharge the respective IGBT will begin to block and the fast acting DC switch will open once the fault is extinguished. This type of protection is very advantageous in MT-VSC systems as you can isolate individual lines without interrupting the entire network. This is especially true in Fig. 3.9 (b) where each line has its own IGBT-CB. While this is a more effective method of protection, it is the most expensive option with further challenges. Unlike Fig. 3.9 (a) case, IGBT-CB cannot begin to block when a fault is detected on the positive line because two or more lines split from the positive or negative node. Since all lines that are connected to a particular node will feed fault on any other line connected to the same node, the faulted line must be detected. Three different methods to achieve this are presented in [52]; they are large current change, rise time, and oscillation pattern.

The large current change method determines which lines are faulted by comparing the current magnitude of all lines feeding the fault. The line with the largest current change in a given time will be chosen as the faulted line. The rise time method measures the rise time of the first wave front of the current.

When a fault is detected, each VSC will measure the rise time of the current in their respective lines. The line with the fastest rise time will be identified as the faulted line. The oscillation pattern method looks for wide pulses without a change in polarity. This identifies the faulted line.

While isolating the fault is important, limiting the amount of fault current is as well. The DC link capacitors contribute high fault currents in a very short amount of time. Typically, capacitor protection is done with snubber circuits. However, the snubber only limits the discharge rate of the capacitor; it does not interrupt the discharge current [6]. The idea of placing a circuit breaker in series with the capacitor is introduced in [38]. The type of circuit breaker chosen is a Capacitor DC Circuit Breaker (CDCCB). The advantage of using a CDCCB is speed: it is a very fast acting device, operating in approximately 10 seconds. This fast operation protects the capacitor from extreme stress and destruction. The voltage will hold because the capacitor does not discharge under fault conditions. This creates a shorter charging time when the VSC is put back on line.

DC protection devices not only protect against overcurrent, but they can also protect against overvoltage. If a converter is lost on an MT-VSC system the voltage on the system will drop, but once the converter is back on line the voltage can overshoot. One method presented to mitigate this problem is the implementation of a chopper circuit [34, 12, 8]. In Fig. 3.10 the addition of an IGBT with a series resistor can be seen.

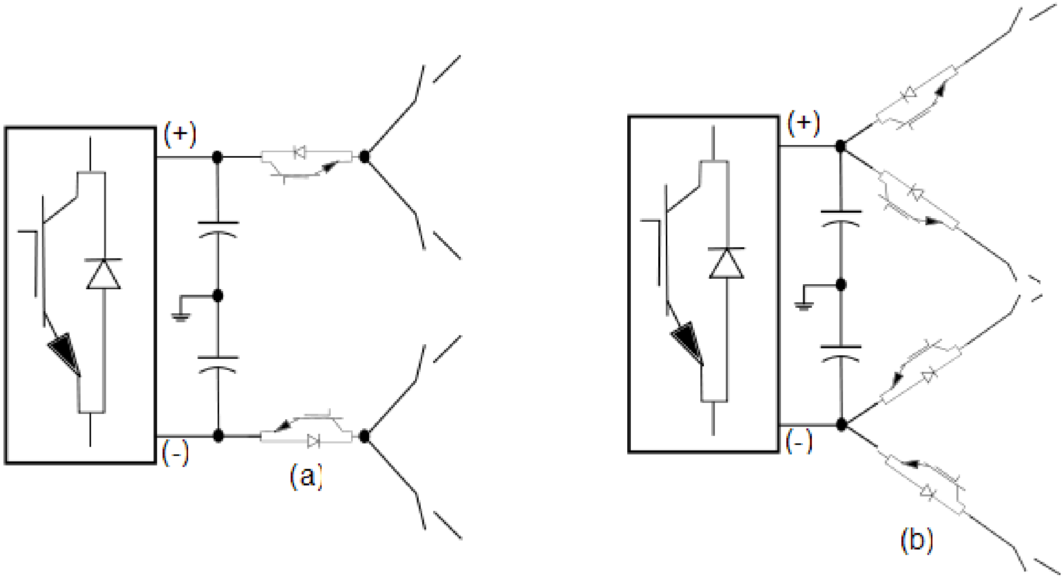

Figure 3.9: IGBT-CB Protection.

3.2.4 Controllers

The previous sections over viewed the devices that interrupt fault conditions. This section will cover the active controllers that will attempt to change the operation of the VSCs under fault conditions in order to keep the system running. Traditionally, a single controller will operate during steady state and fault conditions. This can be seen in [34], where the proposed controller supplies the normal and protective gate trigger pulses. Another option is to implement a parallel controller. The parallel controller is proposed to mitigate overcurrents and overvoltages [31, 32]. Both a current and a voltage controller can be provided in parallel configuration. Within each of the respective controllers, a steady state and a fault controller can be connected in parallel using PI controllers to regulate the current and voltage. Each is running during normal operation but depending on the condition of the system one will take control of the firing pulses.

Overload problems may be solved by implementing some techniques found in motor control [12]. A two-terminal VSC-HVDC system can be looked at as a double-sided converter feeding a motor. When power levels begin to exceed the contingency rating of the system the VSC-HVDC system can enter ”regenerative braking mode,” returning the power back to the AC grid. This is an alternative to using a chopper circuit as the energy is not dissipated, rather it is redirected.

As mentioned, the loss of a converter can lead to overvoltages in the system and can adversely affect MT-VSC systems. To combat this problem an advanced

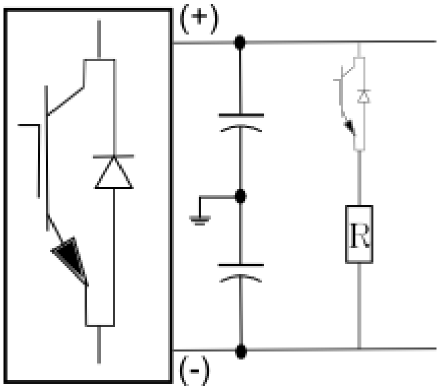

Figure 3.10: Overvoltage Chopper Circuit.

DC voltage controller (ADCVC) is proposed in [36]. This ADCVC operates in two stages; lower and higher hierarchical. The lower hierarchical control operates during normal system operation. This lower hierarchical controller is responsible for maintaining active power, reactive power and DC voltage. The higher hierarchical controller monitors the system and only reacts during transient disturbances, i.e., converter loss in MT-VSC. The higher hierarchical controller recognizes transient disturbances by changes in the local voltage and current, as the loss of a converter will redirect power flow in the DC network. Upon recognition of a disturbance, the ADCVC will take control and alter the performance of its respective converter or shut down the converter in order to protect it from harm in some cases. The idea of lower and higher controllers is similar to coordination of protective devices on AC systems.

3.2.5 Current Limiting Techniques

There are several techniques that attempt to limit the current under a faulted condition. Some of the fault current limting techniques are:

- Superconductor
- Positive Temperature Coefficient
- Saturaed Inductor
- Power Electronics

The supercondcutor technique uses a superconductor as a part of the transmission or distribution line. Under normal conditions the superconductor resistance will be nearly zero. When a faulted condition is detected the superconductor will begin to increase its resistance in order to limit the current. This technique require a special cooling system s well as separate protection for the supercondcutor [37, 24].

The Positive Temperature Coefficient is similar to the superconductor method but uses a variable resistor that is temperature controlled. Under normal condition the current is low and therefore the resistance is low. Under faulted conditions the increased current will cause an increase in temperature thus increasing the resistance of the resistor. While this technique is less complex than the supercondcutor it has low capacity for current and voltage. Therefore under high fault conditions the resister can fail, opening the circuit[37].

The saturated inductor places an inductor in the line and uses a separate exciting circuit to drive the inductor into saturation, keeping the resistance low. Under faulted conditions the inductor will be pulled out of saturation, increasing resistance and decreasing current. This method requires the use of a large iron core, increasing size and cost. Also, the inductor on limits the rate of rise and not the maximum fault level[37, 50]. Also,the increased inductance in the line adversely affects the response to the fast load dynamics.

The use of power electronics suggests limiting fault current by switching of the bus circuit breakers [37, 28]. However,it is not easy to switch large current and required inductance could make the dynamic response of normal operation sluggish. Also, if a fault is permanent then limiting the fault current in order to ride through the fault is not necessary.

4. Proposed Protection Method and Algorithm

4.1 Operation Modes

The novel protection method and algorithm for the DC bus microgrid system is proposed in this research. Unlike may other methods [53, 52], the proposed scheme does not require a complete shutdown of the grid. Rather, only the affected section of the microgrid is isolated and de-energized. This is achieved through use of a ring bus configuration for the main DC bus, creating several zones of protection within the ring bus, and installing a grounding resistor to limit the fault current. This is done for both the positive and negative bus. The proposed protection scheme can be split into three sections:

- Fault Detection and Isolation
- Breaker Failure Detection
- Reclose and Restore

The ring bus will be split into zones and each zone is monitored by an Intelligent Electrical Device (IED). The IED will continually monitor the current through it's assigned breakers. Once a fault is detected the IED will open the zone breakers. The IED will then ensure that all of the breakers have opened and that the faulted zone is de-energized. If the zone has not been de-energized the zone IED will send signals to adjacent IED until the fault is extinguished. If the zone was successfully de-energized the IED will attempt to restore the faulted zone by reclosing the breakers. If a fault is then detected the zone breakers are again tripped and the zone is isolated. A flow chart of the protection logic can be seen in Fig. 4.2.

4.1.1 Fault Detection and Isolation

The microgrid under study consists 12 zones of protection. Each zone is classified by the type of energy device it has been assigned to. The zones can be split into 4 categories: uni-directional, bi-directional, load, and link which is shown in Fig.4.1. Each zone consists of 2-3 breakers and a section of cable. A local IED is assigned to each zone. The IED will monitor and control each of the breakers within its assigned zone. Each IED is programmed with the specific set of rules that define a normal zone operation. This is dependent on the source that the IED is monitoring. It should be noted that due to the ring bus configuration, current has several paths to flow. Therefore several normal operating conditions must be accounted for, and they must all fail before a fault is declared. Once fault has been detected all breakers in the affected zone are tripped, regardless of the pole the fault is on. This is done to keep the microgrid and converters in balance. In the examples specific rules that are needed to define a fault are provided. One rule for each zone type is given.

Once the faulted segment is isolated, the remainder of the sources and loads can continue to operate on the ring bus. Even with multiple faulted segments, the system can operate partially if the segments from the main source to some loads are intact.It has been assumed that the segment controllers can detect it and open/close Solid State Circuit Breakers in $500\mu sec$. For example, turn-off time for an IGCT is approximately $11\mu sec$.

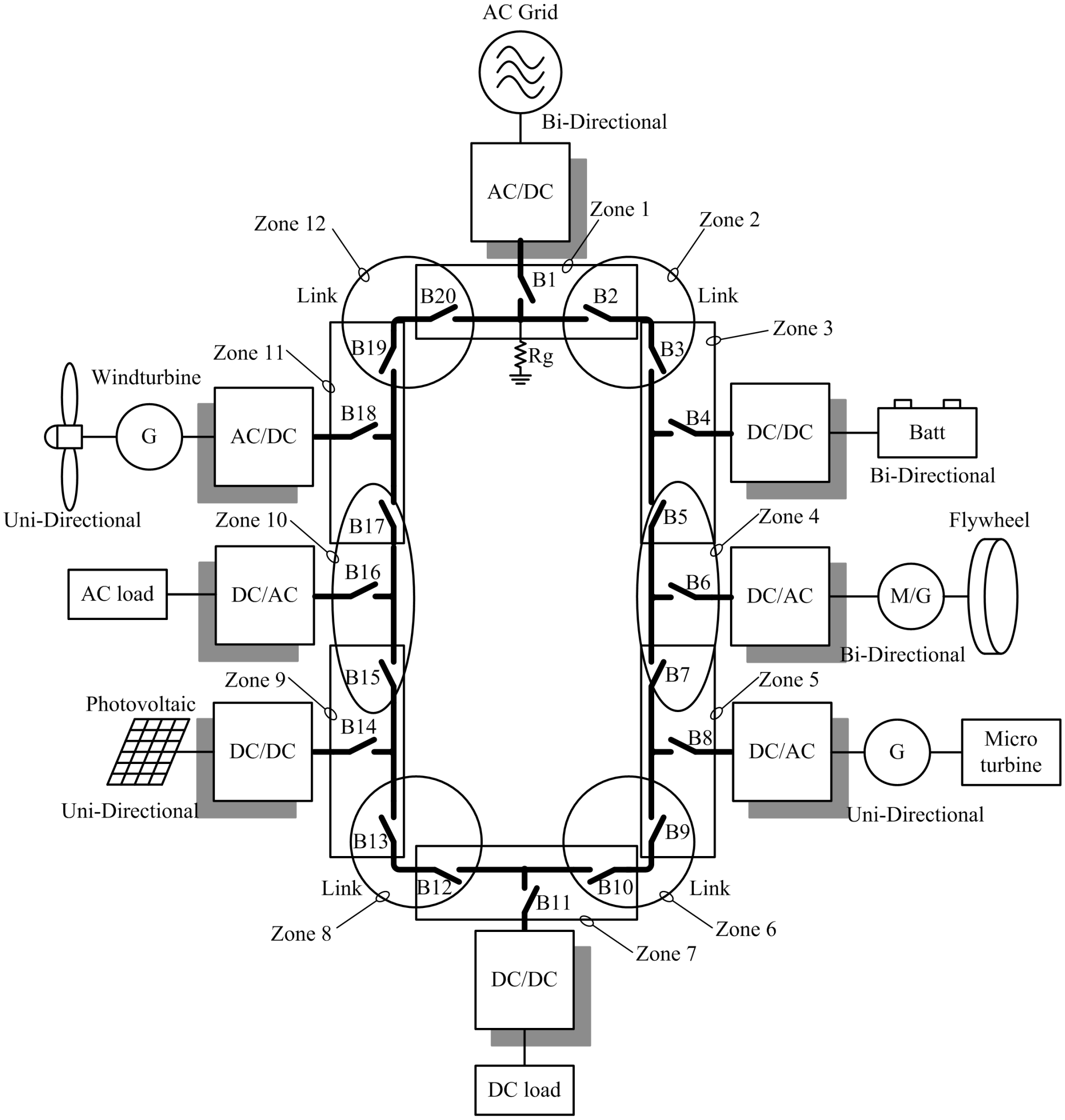

Figure 4.1: Microgrid Protection Zones

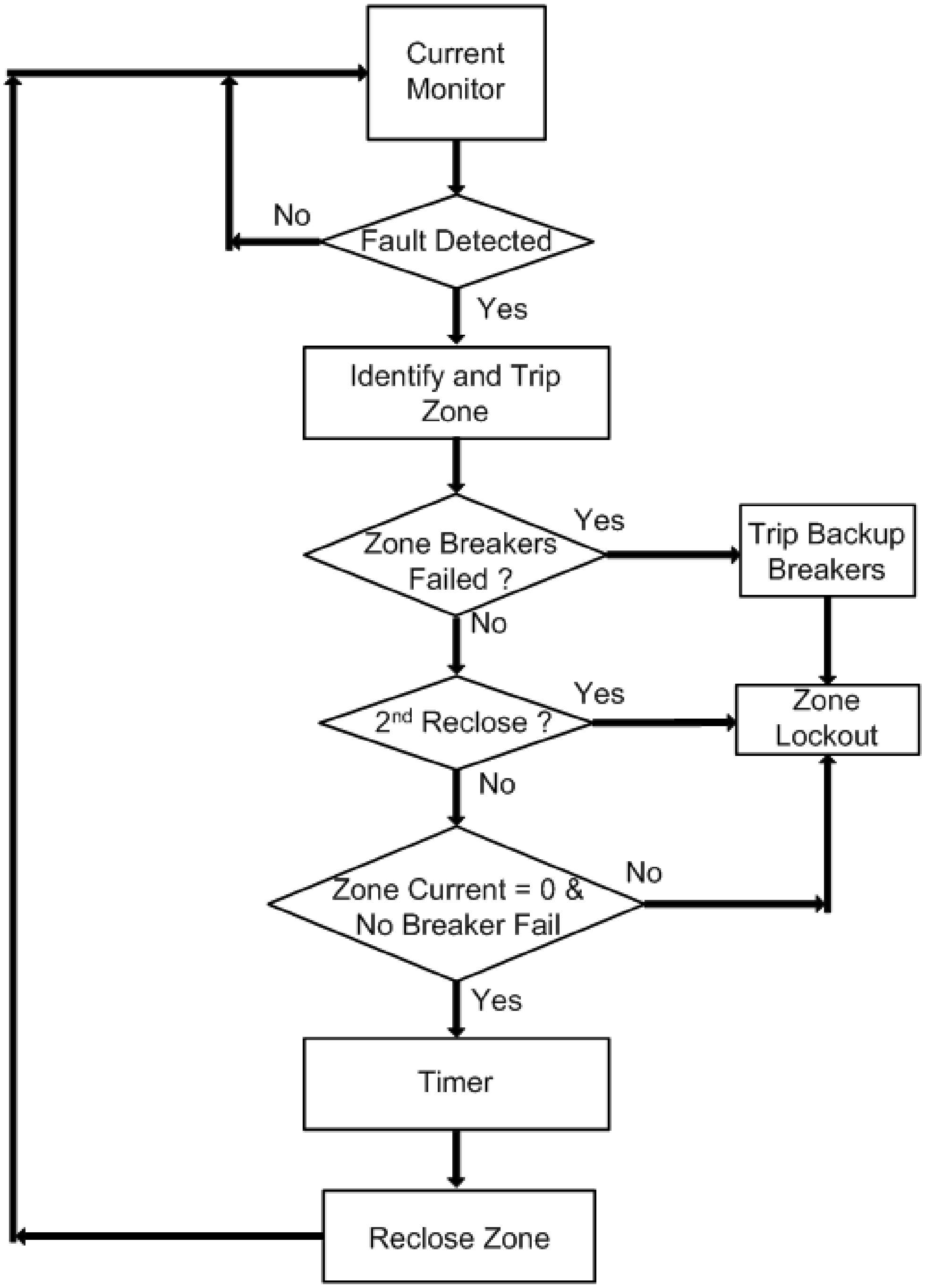

Figure 4.2: Algorithm Flow Chart

- Uni-Directional Source Zones (Zone 5 Example)

$$I_{B7} = I_{B8} + I_{B9} \tag{4.1}$$

$$I_{B8} = I_{B7} + I_{B9} \tag{4.2}$$

$$I_{B9} = I_{B7} + I_{B8} \tag{4.3}$$

- Bi-Directional Source Zones (Zone 3 Example)
  - Discharge Mode

$$I_{B3} = I_{B4} + I_{B5} \tag{4.4}$$

$$I_{B4} = I_{B3} + I_{B4} \tag{4.5}$$

$$I_{B5} = I_{B3} + I_{B4} \tag{4.6}$$

  - Charge Mode

$$I_{B3} = I_{B5} - I_{B4} \tag{4.7}$$

$$I_{B4} = I_{B3} + I_{B4} \tag{4.8}$$

$$I_{B5} = I_{B3} - I_{B4} \tag{4.9}$$

- Load Zones (Zone 7 Example)

$$I_{B10} = I_{B12} - I_{B11} \tag{4.10}$$

$$I_{B11} = I_{B10} - I_{B11} \tag{4.11}$$

$$I_{B12} = I_{B10} - I_{B11} \tag{4.12}$$

- Link Zones (Zone 8 Example)

$$I_{B12} = I_{B13} \tag{4.13}$$

$$I_{B13} = I_{B12} \tag{4.14}$$

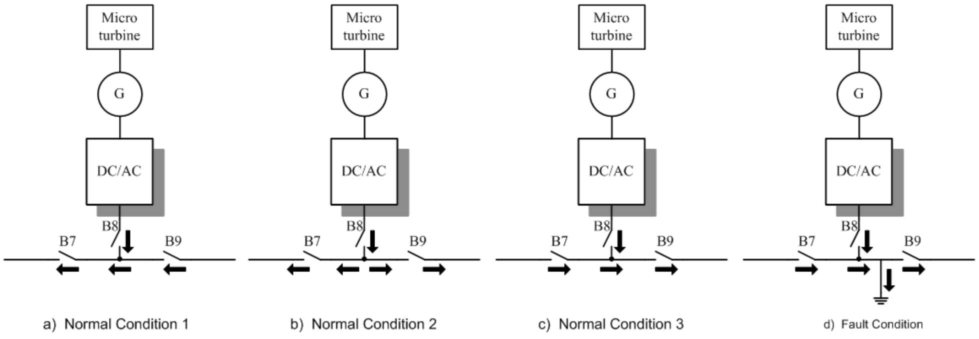

Figure 4.3: Uni-Directional Zone: Normal and Faulted Current Flow

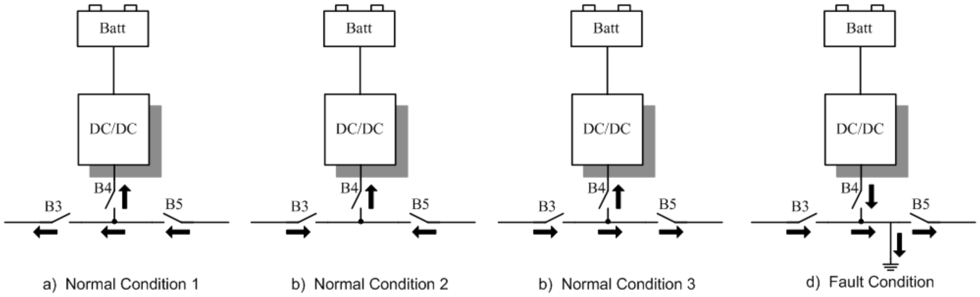

Figure 4.4: Bi-Directional Zone: Normal and Faulted Current Flow

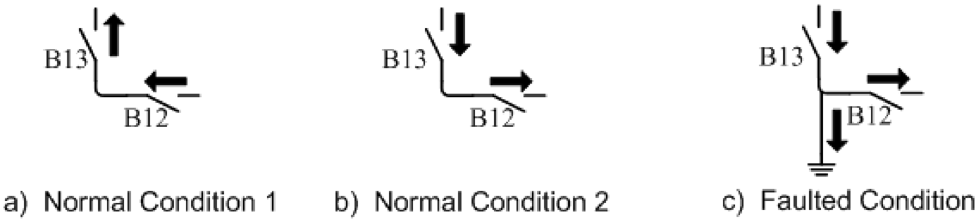

Figure 4.5: Link Zone: Normal and Faulted Current Flow

4.1.2 Breaker Failure Detection

Each zone IED continually monitors the status (open/closed) on their respective zone breakers. Under normal conditions this can be used for information purposes to operators of the microgrid. Once a fault inside a zone is detected and trip signals are sent, the IED waits 1 second then enters breaker monitoring mode. The breaker monitoring mode operates under two different conditions:

- Status and Current
- Current

4.1.2.1 Status and Current

In the Status/Current conditions the zone IED flags that a trip to all breakers has been sent. The IED then checks to see if all of the breakers are showing a closed status. If a breaker status is closed and the IED expect it to be open a breaker fail condition is suspected. The IED must also confirm that current continues to flow is the faulted zone. If both the closed status and current in the zone are detected the faulted zone IED will then send a signal to the appropriate zone controller to trip its zone breakers. For example, if a fault is detected in Zone 4, but Breaker 5 fails, then a signal from the Zone 4 IED would be sent to the Zone 3 IED. The Zone 3 IED would trip its associated breakers (Fig.4.1). At this point both Zones 3 and 4 have been de-energized and locked out. Locking out the zone means that the controllers will not try to automatically reclose and restore the zones. Restoring the zones after a lockout condition requires a

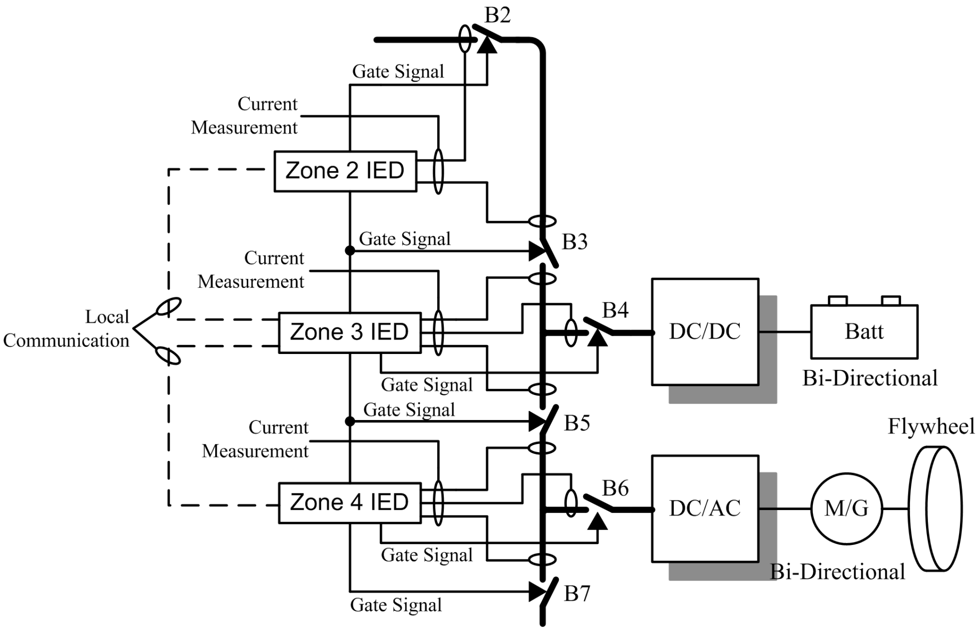

Figure 4.6: Zone Controller Connections

manual restore, after the fault had been removed from the system. This condition requires two pieces of information, but extinguishes the fault with the least amount of impact to the DC bus.

4.1.2.2 Current

If all of the breakers in the faulted zone are providing an open status, but the IED continues to read current in the zone then all of the adjacent zones will be tripped. Using the Zone 4 example, but this time all of the breakers provide an open status. The Zone 4 IED would send signals to both the Zone 3 5 IED's, de-energizing Zones 3,5 5 (Fig.4.1). This condition ensures that the fault will be extinguished even if the IED receives a false status from the breakers. However, it requires large sections of the grid to be de-energized.

4.1.3 Reclose and Restore

Once the faulted zone had been tripped and none of the breakers failed, the IED will the reclose and restore. Often, faults are temporary due to debris or animals coming in contact with the cable or line. The temporary faults will clear themselves after current flows through the unwanted ground source. The reclose and restore mode allows the IED to autonomously restore power back to the de-energized zone. This is done by waiting 1 second after the trip signals have been sent. After that 1 second the IED will send close signals to all of the breakers. If the fault has been successfully cleared, the microgrid will continue to run normally. However, if the fault is permanent and it is detected after the first reclose, all of the zone breakers will again be tripped and the zone will be locked out.

4.2 Solid State Circuit Breakers

Due to the limitations of fuses and traditional circuit breakers in DC systems, a solid state circuit breaker is utilized. When selecting a solid-state circuit breaker there are several options: GTO, IGBT, and IGCT. GTOs offer a high blocking voltage capability and a low on stare voltage, but suffer from slower switching speeds [26, 1]. IGBTs are widely used in the low voltage ($< 1200V$) systems [25]. IGBTs offer fast interruption time (10μsec) and an ability to withstand short circuits [1]. The disadvantage when using a IGBT is that they suffer from high conduction losses [1, 49, 51, 26]. IGCTs offer the lower conduction losses of a thyristor with the turn-off capability of a transistor. Like the IGBT,

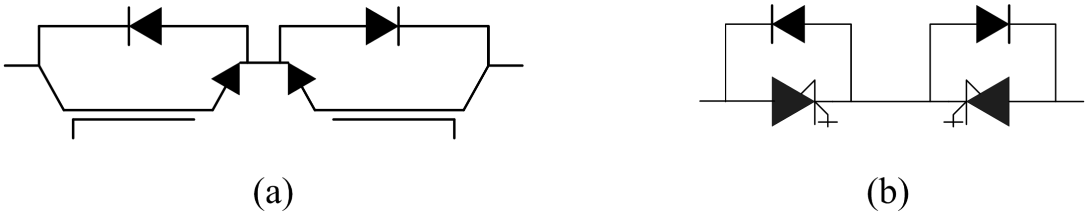

Figure 4.7: a)Bi-directional IGBT circuit breaker. b)Bi-directional IGCT circuit breaker.

the IGCT offers high voltage and current ratings but does not suffer from high conduction losses. The IGCT has a slower switching speed than the IGBT, but when used as a circuit breaker is may not be a concern [51, 49]. In order for the microgrid to allow power flow in either direction the IGCT-CB needs to be bi-directional. The bi-directional IGCT-CB actually consists of two IGCTs placed in series with one opposing the other Fig. 4.7.

4.2.1 Grounding

The magnitude of a ground fault current is dependent on the distance from the source that the fault occurs and the resistance of the ground fault path. The fault current from the source an converter capacitors can be given as (4.15).

$$I_{fault}(t) = \frac{E_s}{R_{eq}}(1 - e^{-\frac{R_{eq}}{L_{eq}}t}) + \frac{E_s}{R_c}e^{-\frac{t}{R_c C_{eq}}} \tag{4.15}$$

Where E_s is the line voltage, R_{eq} and L_{eq} is the equivalent system resistance and inductance, and R_c and C_{eq} is the equivalent series resistance and equivalent capacitance of the converter capacitors. It can be seen in (4.15) that the fault current magnitude determined by R_{eq}. The value of R_{eq} can be altered depending on the grounding method of the system. The grounding options are: 1) solid grounding; 2) low-resistance grounding; 3) high-resistance grounding;

and 4) ungrounded [16]. Although ungrounded systems are used in some applications to avoid the effect of low-resistance pole-to-ground fault and stray current, ungrounded systems are sensitive to changes in the grounding plane and can be dangerous especially under abnormal fault conditions [27, 45]. The advantages of the grounding in a DC distribution system include predictable operating conditions, minimum voltage stress for the system components, and easier fault detection [27]. The line-to-ground faults are the most common types of faults in industrial distribution systems [16] and the ground fault current can be limited by using the resistance grounding. Since the typical power electronics converters connected in the LVDC systems cannot feed large fault currents, it would be beneficial to reduce the fault current to an appropriate level for detection and extinction. However, some protective devices are still needed even with this low resistance grounding scheme, because the fault current cannot be sustained [16].

It is a common practice to ground power systems at one point only and as close to the source as possible [27]. Multiple ground points could form unnecessary circulating current paths. Possible grounding point for a DC system is either one of the poles or the mid point of the bus, and it has been reported that the balanced DC side grounding significantly reduces circulating current compared to the AC side neutral-grounded system [27]. Although the ground resistors can be used to detect the ground fault as well, it is not able to identify the location of the fault because of the single ground point practices.

In this paper, a resistance grounding to the balanced DC bus mid point has been chosen for a well-defined pole-to-ground voltages and robustness to imbalance [47, 27]. The resistor was sized so that the fault current would not drastically exceed the load current of the system. Sizing a grounding resistor for a DC system only requires the use of Ohms law, as seen in equation 4.16

$$R_{gr} = \frac{E_s}{I_f} \tag{4.16}$$

Where R_{gr} is the grounding resistor size, E_s is the system voltage and I_f is the desired fault current level.

5. Simulation Results

To verify the proposed protection scheme, computer simulations have been performed using OrCAD/PSpice. The microgrid model can be seen in 5.1 Simulation parameters can be found in Table 5.1 The algorithm was programmed and simulated using MATLAB and can be found in the Appendix. The OrCAD/PSpice figures illustrate the fault current in the affected zones; while the MATLAB figures show the IED control signals. A negative pole line-to-ground fault in zone 1 is simulated at 9.5$msec$. Fig. 5.2 shows the line-to-ground fault current when no grounding resistance has been installed. It can be seen that the current magnitude in the zone drastically increases from 50A of load current to 18kA.

Next, the grounding resistor was installed at the neutral point of the AC grid converter. Fig. 5.3 illustrates the affect the grounding resisance has on the fault current magnitude. It can be seen that the grounding resistor limited the fault current from 18kA to just over 200A. In Fig.5.7 it can be seen that at the event of the fault at 9.5$msec$ the Zone 1 IED detects the fault and send trip signals to the Zone 1 breakers. The status of the breakers can be seen in Fig. 5.6. The voltage at the AC and DC loads can be seen in Fig. 5.4.

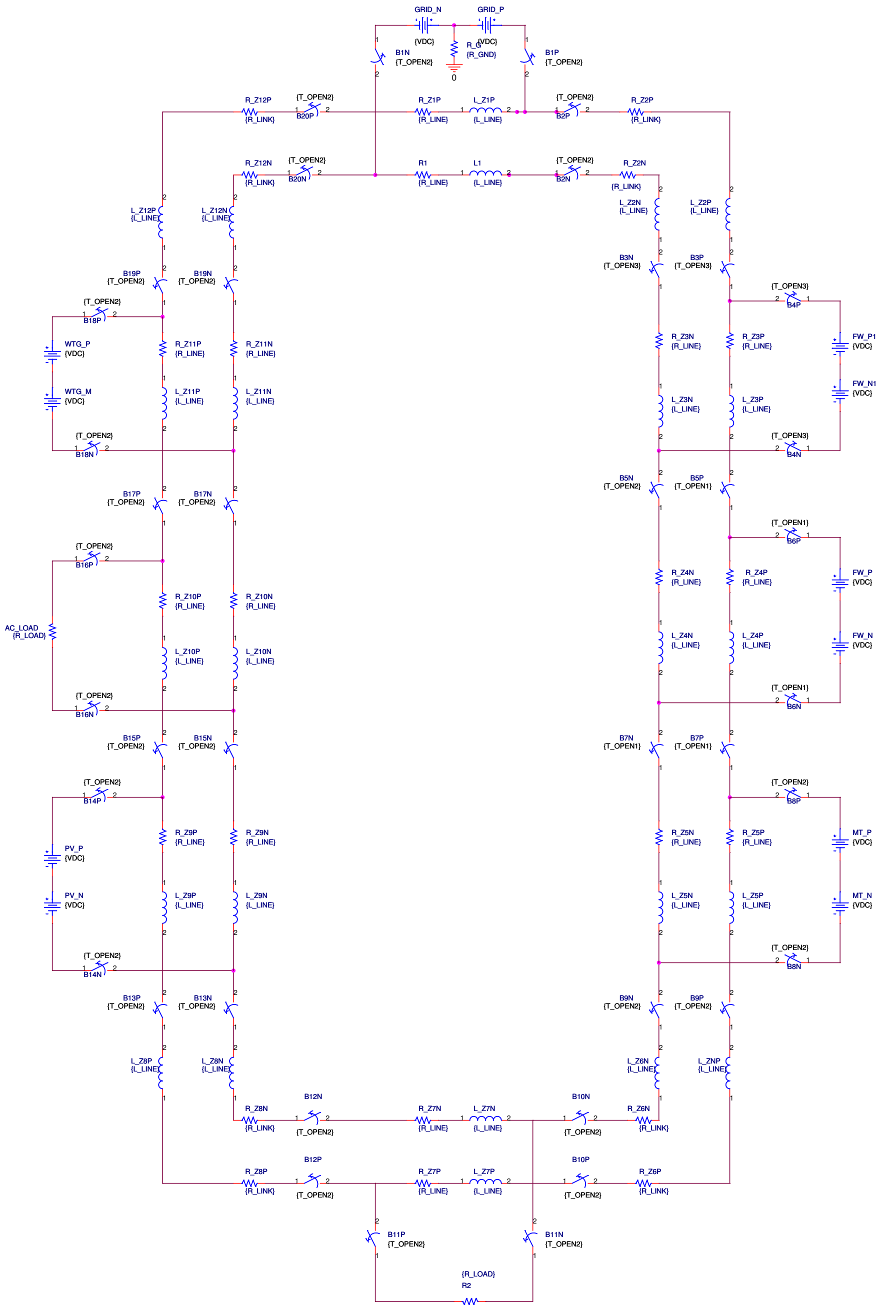

Figure 5.1: OrCAD/PSpice Simulation Model

Table 5.1: Simulation Parameters.

Name	Value
VDC	$350V$
R_{LOAD}	1.7Ω
R_{LINE}	$1.6m\Omega$
L_{LINE}	$640nH$
R_{LINK}	$0.63m\Omega$
L_{LINK}	$256nH$
R_{GND}	1.75Ω

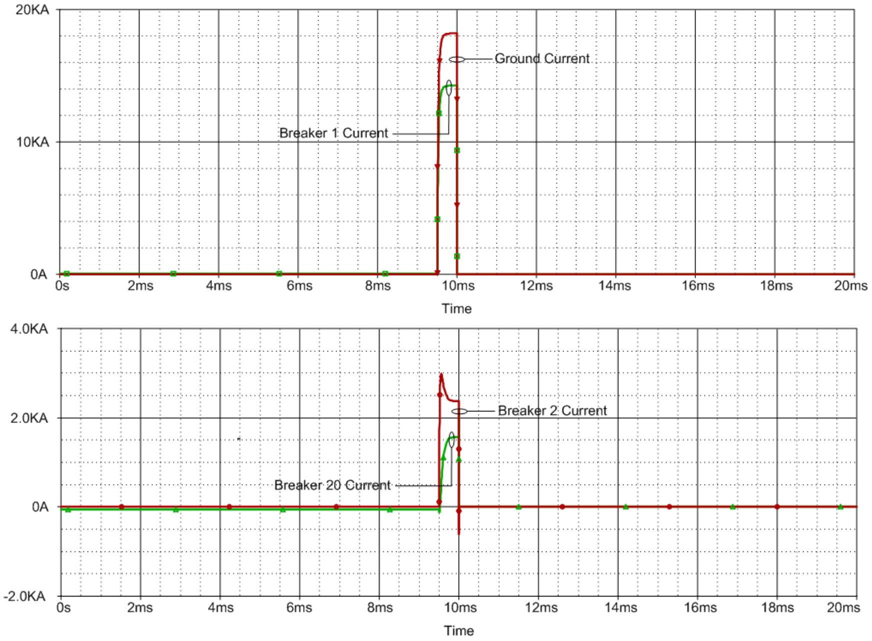

Figure 5.2: Analytical Simulation Circuit for Line-to-Ground Fault in Zone 1 Without Resistance Grounding.

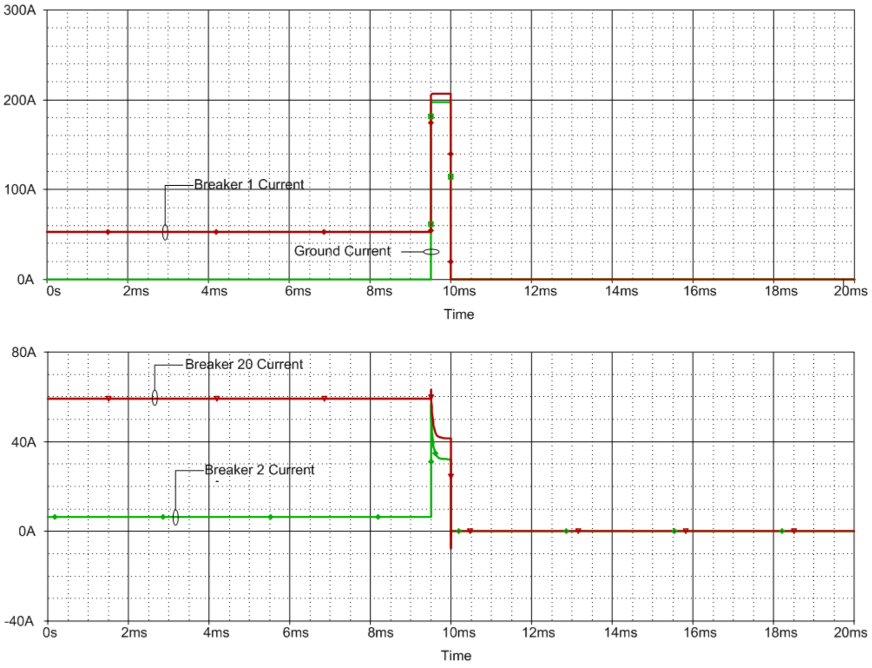

Figure 5.3: Analytical Simulation Circuit for Line-to-Ground Fault with Resistance Grounding.

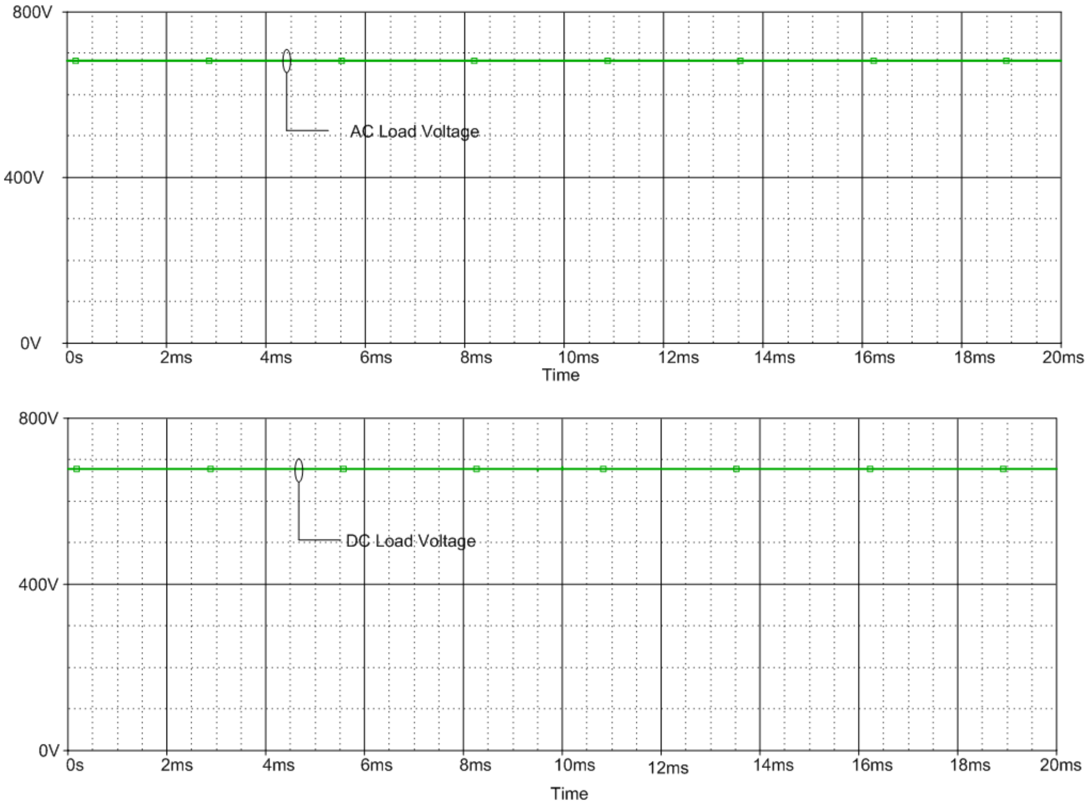

Figure 5.4: Voltage at AC and DC Loads during a Line-to-Ground Fault with Resistance Grounding

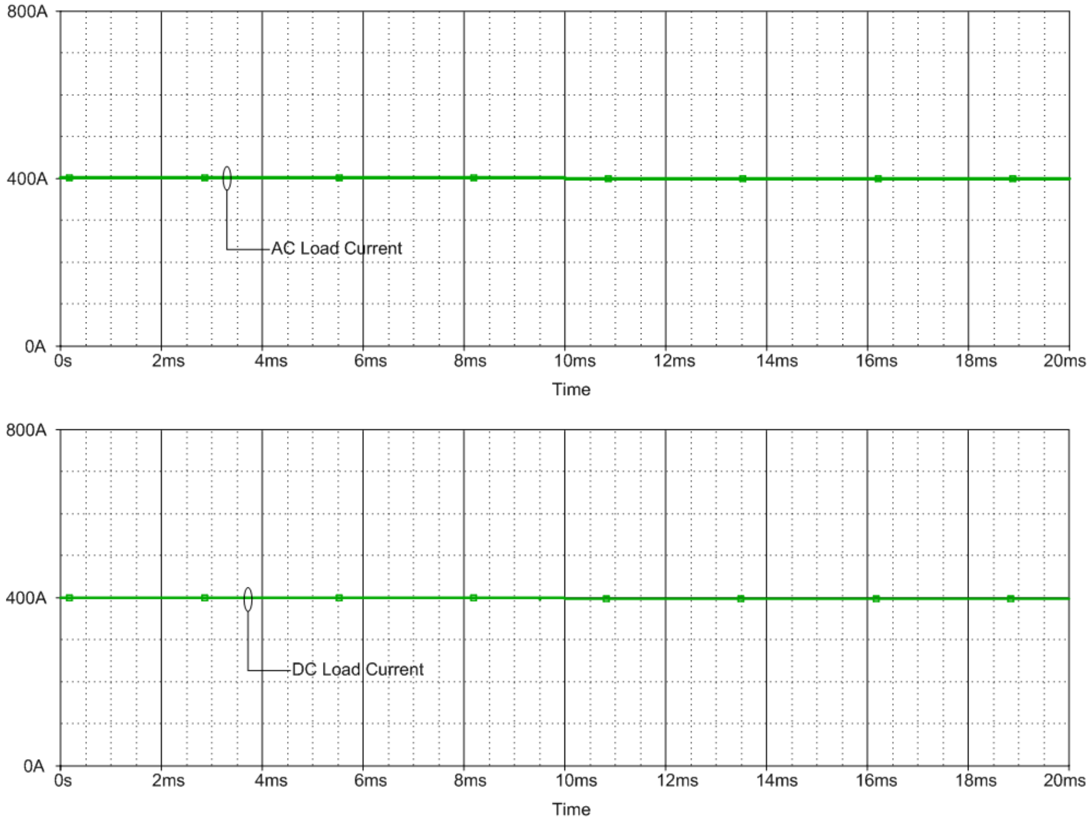

Figure 5.5: Current at AC and DC Loads During a Line-to-Ground Fault with Resistance Grounding

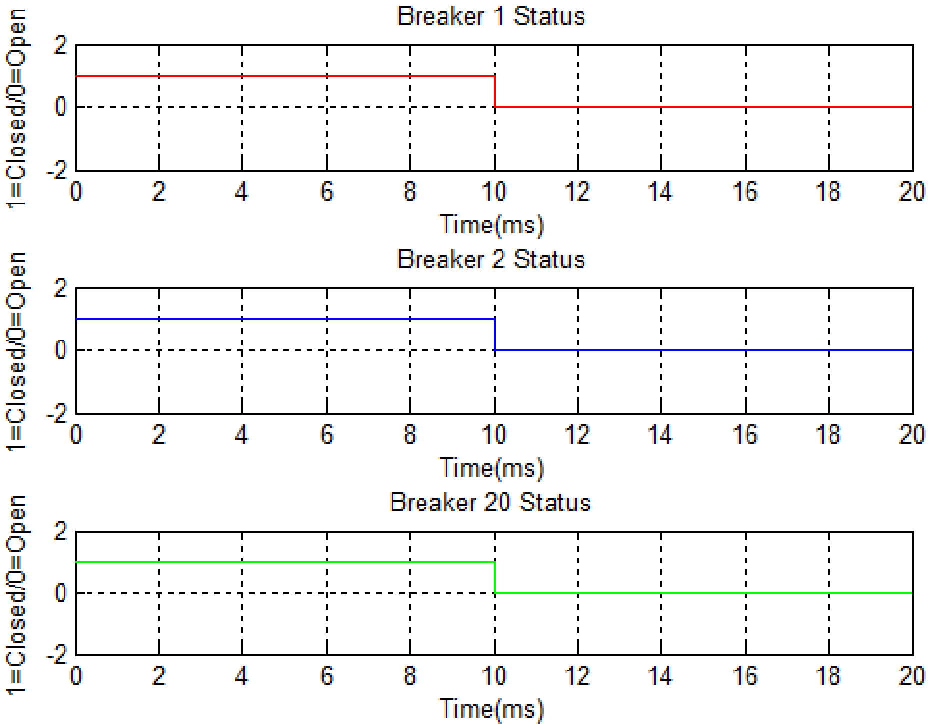

Figure 5.6: Zone 1 Circuit Breaker Status During a Line-to-Ground Fault

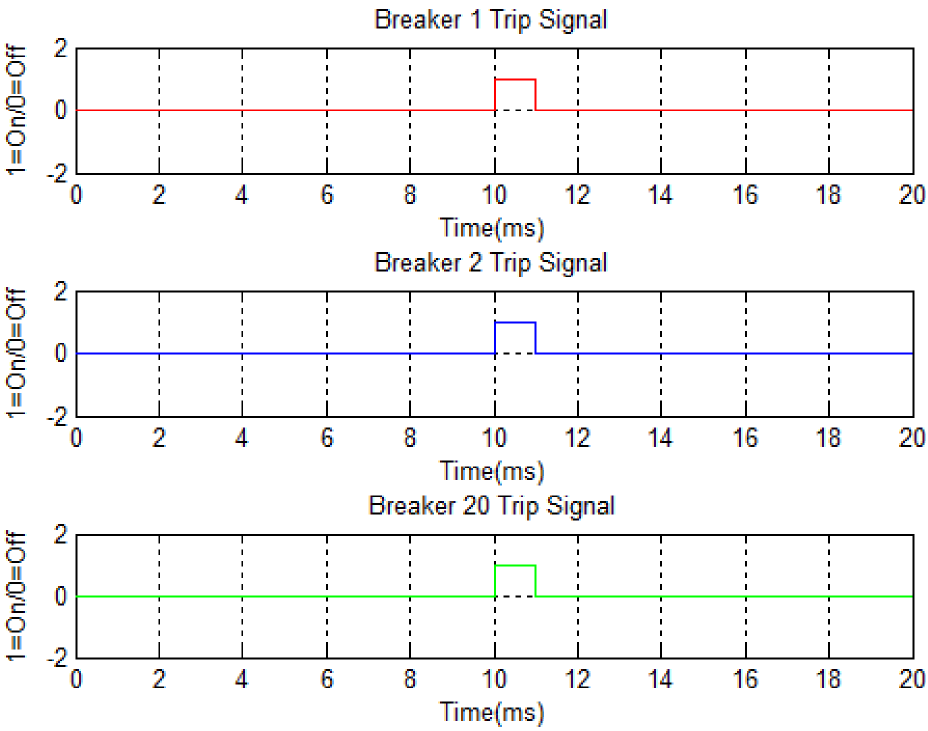

Figure 5.7: Zone 1 IED Trip Signals During a line-to-Ground Fault

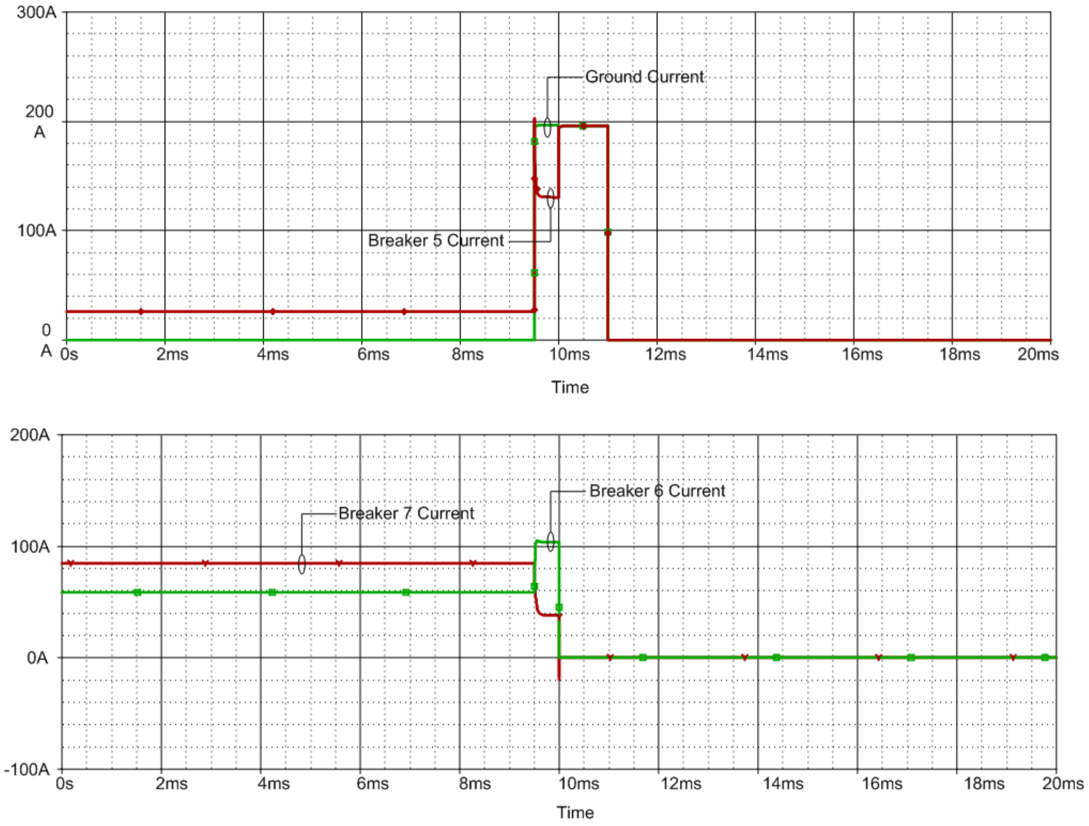

Figure 5.8: Zone 4 Current with Breaker 5 Failing to Open

A breaker failure condition was simulated in Zone 4. A negative pole line-to-ground fault was placed in Zone 4, but breaker 5 fails to open. At this point a breaker fail condition is recognized by the Zone 4 IED, sending a signal to the Zone 3 IED to trip breakers 3 and 4. Fig.5.8 shows the fault current in the zone until the breaker fail sequence is complete.In 5.9 the current in Zone 3 is provided. Fig.5.10 and Fig.5.11 provides the status of the Zone 3 and 5 breakers, respectively.

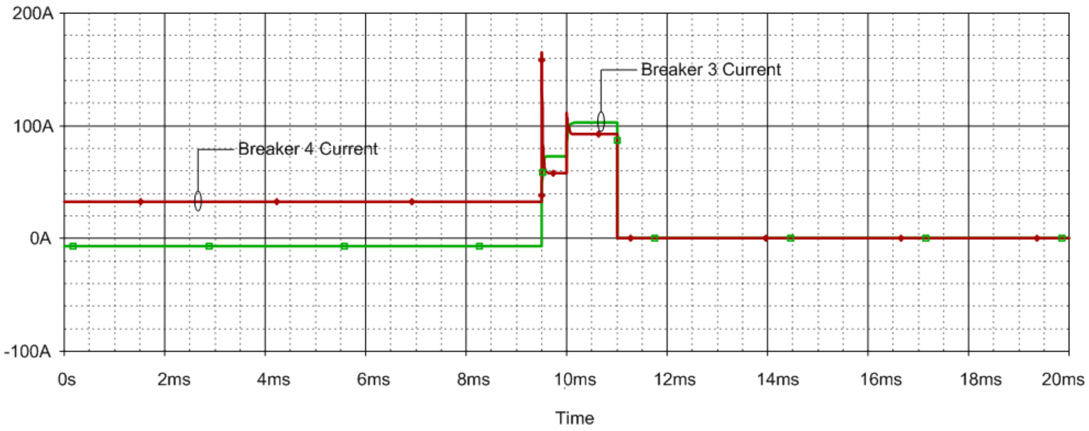

Figure 5.9: Zone 3 with Breaker 5 Failing to Open

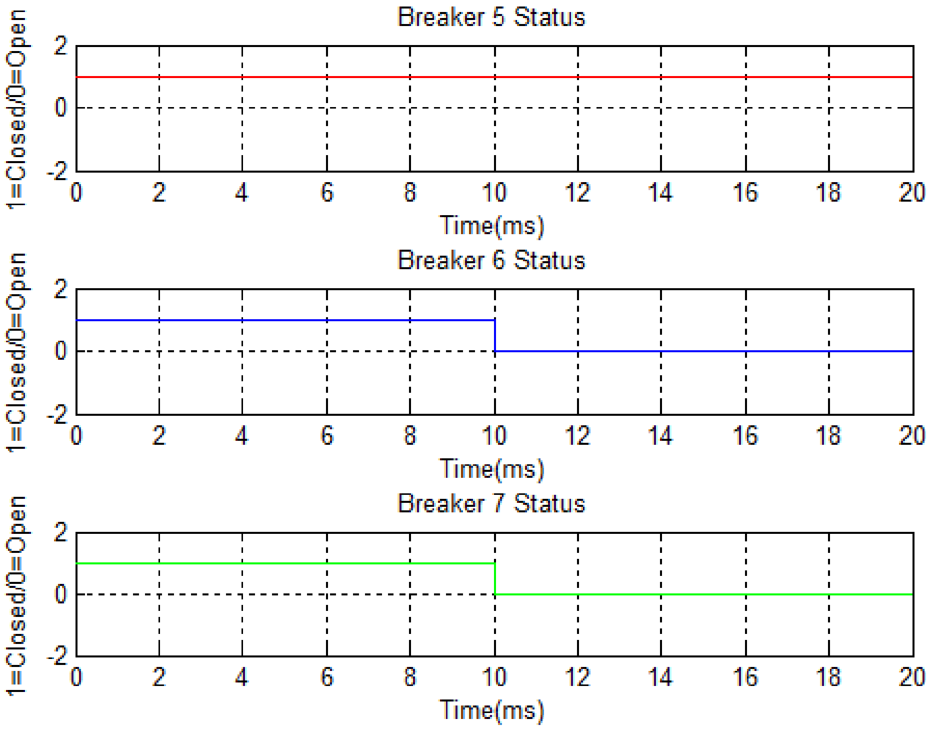

Figure 5.10: Zone 4 Breaker Status with Breaker 5 Failing to Open

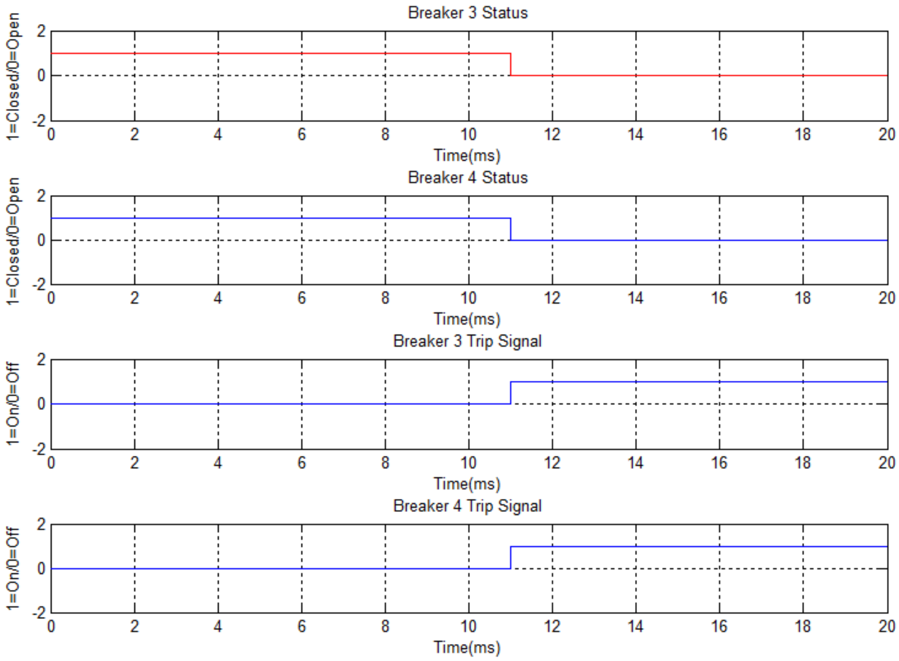

Figure 5.11: Zone 3 Breaker Trip Signals After Breaker 5 Fails to Open

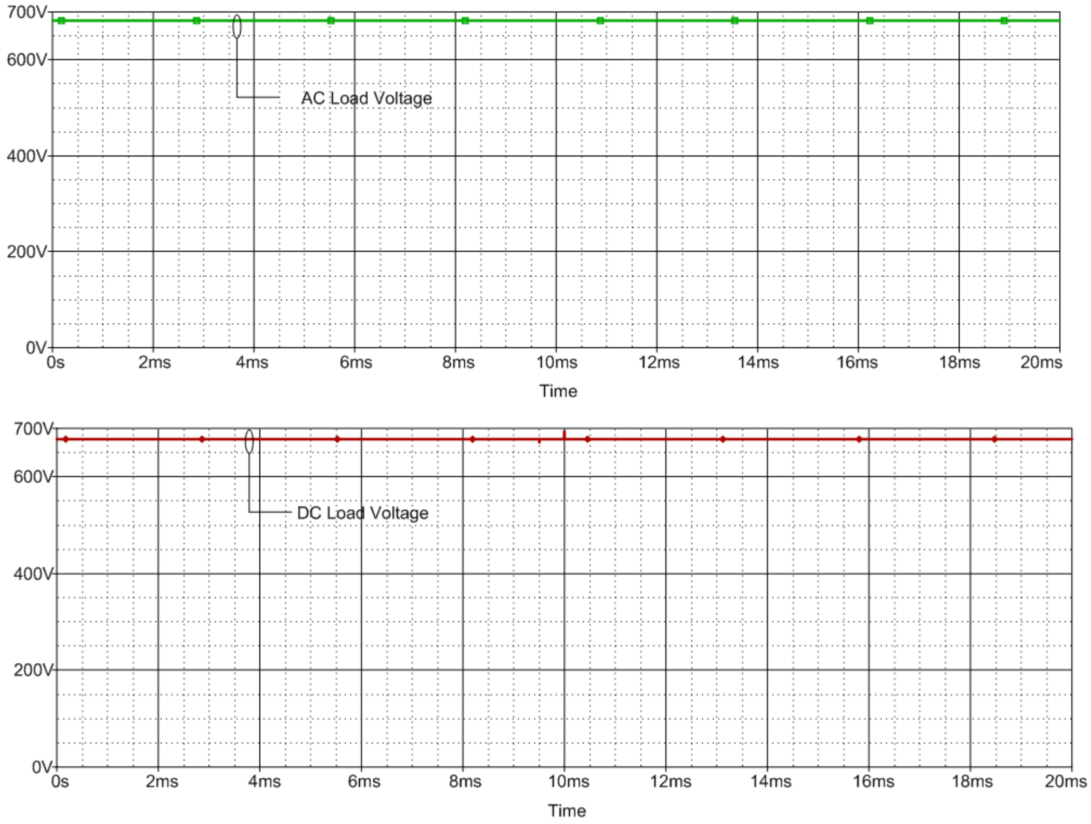

Figure 5.12: DC Voltage at Loads During a Zone 4 Breaker Fail

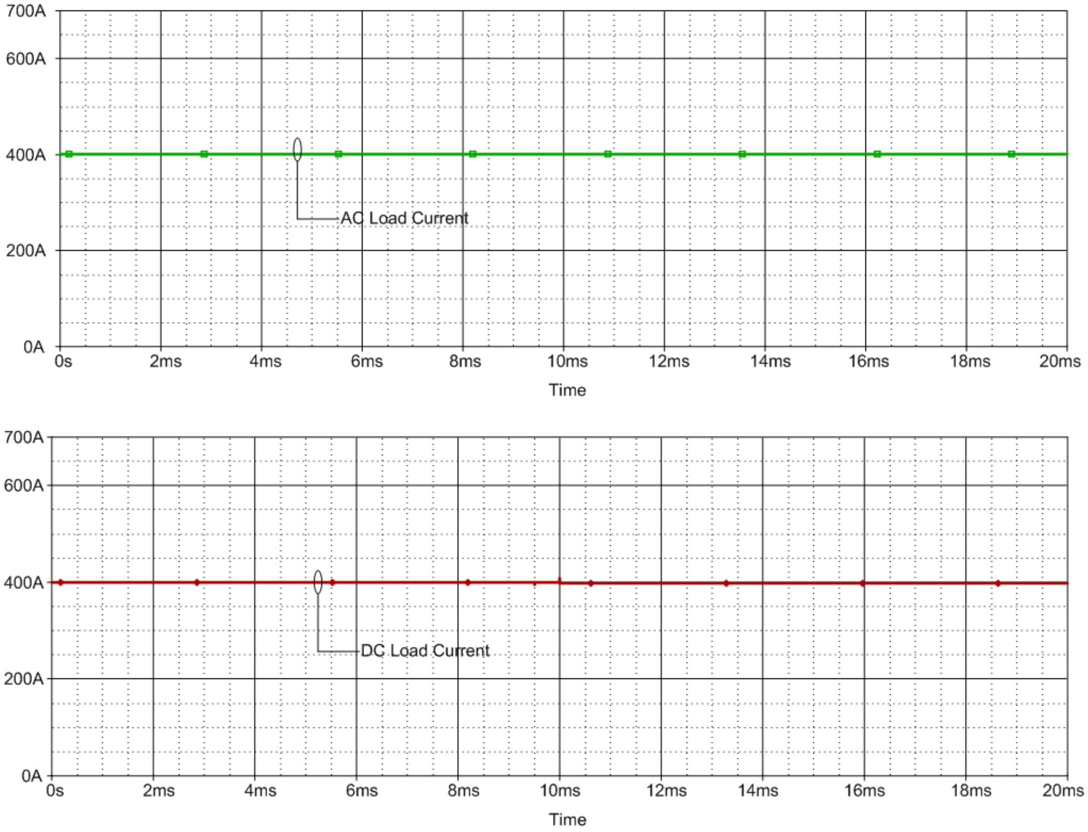

Figure 5.13: Current at Loads During a Zone 4 Breaker Fail

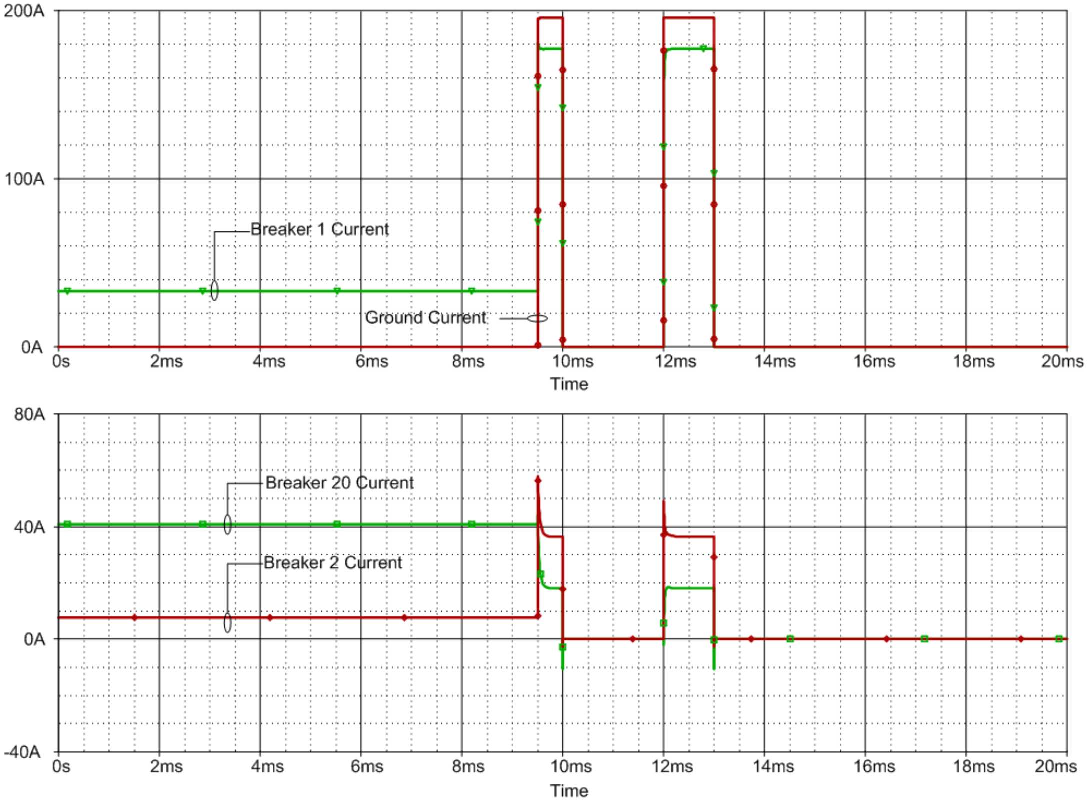

Figure 5.14: Zone 1 Current During a Reclose and Lockout Cycle

Finally, the reclose sequence can be seen in Figs. 5.14, 5.15, 5.16 and 5.17. Again, a fault is simulated in Zone 1 at 9.5$msec$, and the Zone 1 IED does not detect a breaker fail condition. The IED then enters the reclose and restore mode, and closes breaker 1, 2 and 20 at 12$msec$. In this case it was simulated that the fault did not clear. Therefore, when the breakers are re-closed if the fault is detected, the IED trips and locks out the zone breakers.

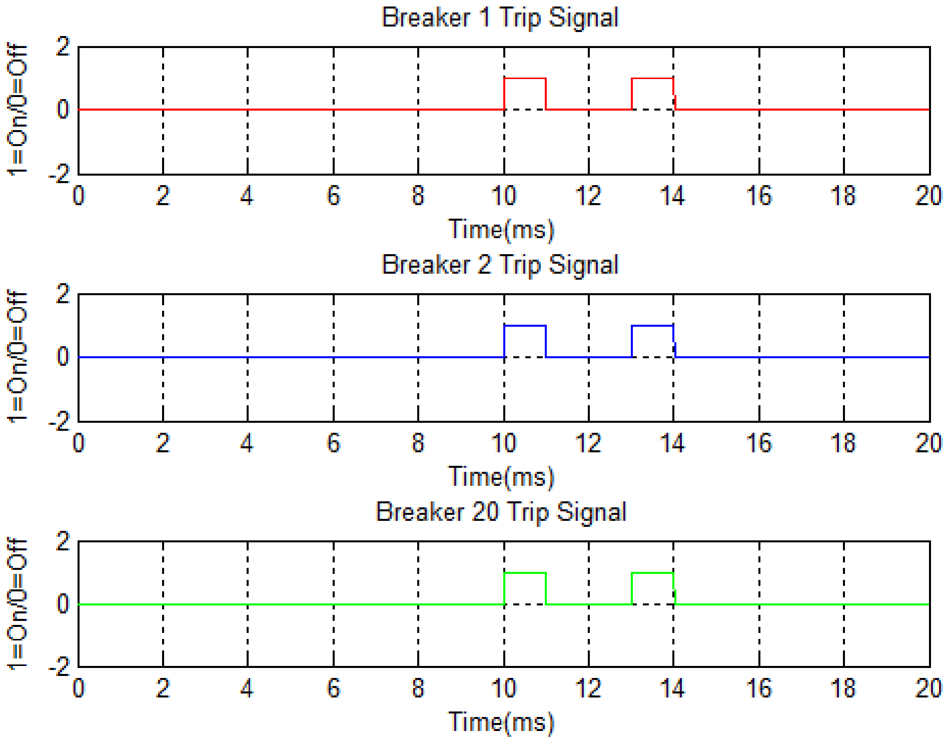

Figure 5.15: Zone 1 Reclose Cycle Trip Signals

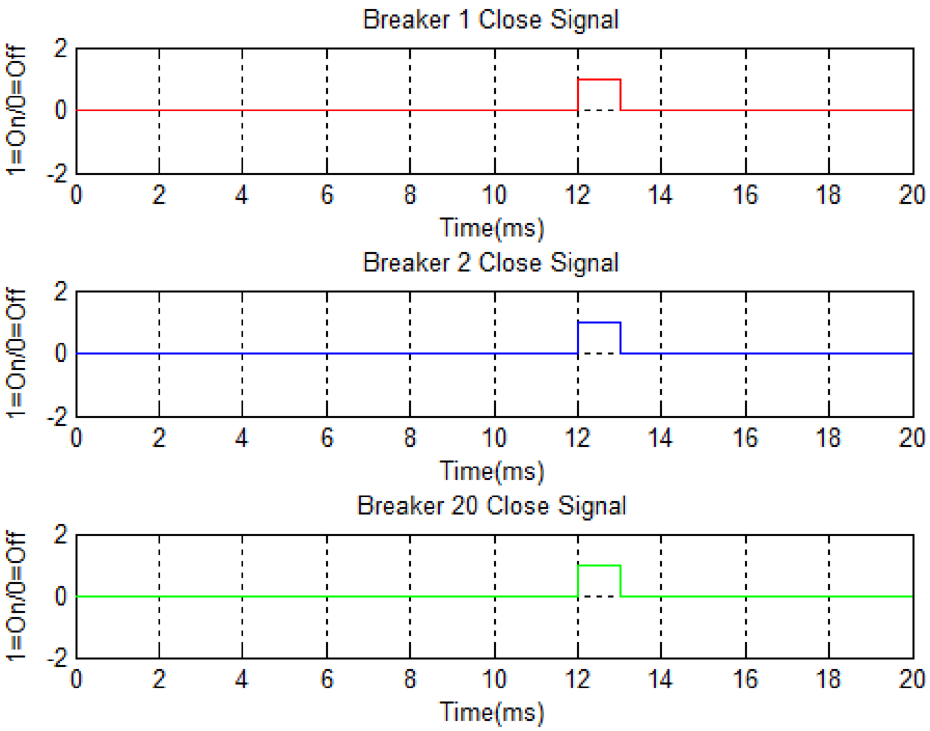

Figure 5.16: Zone 1 Reclose Cycle Close Signals

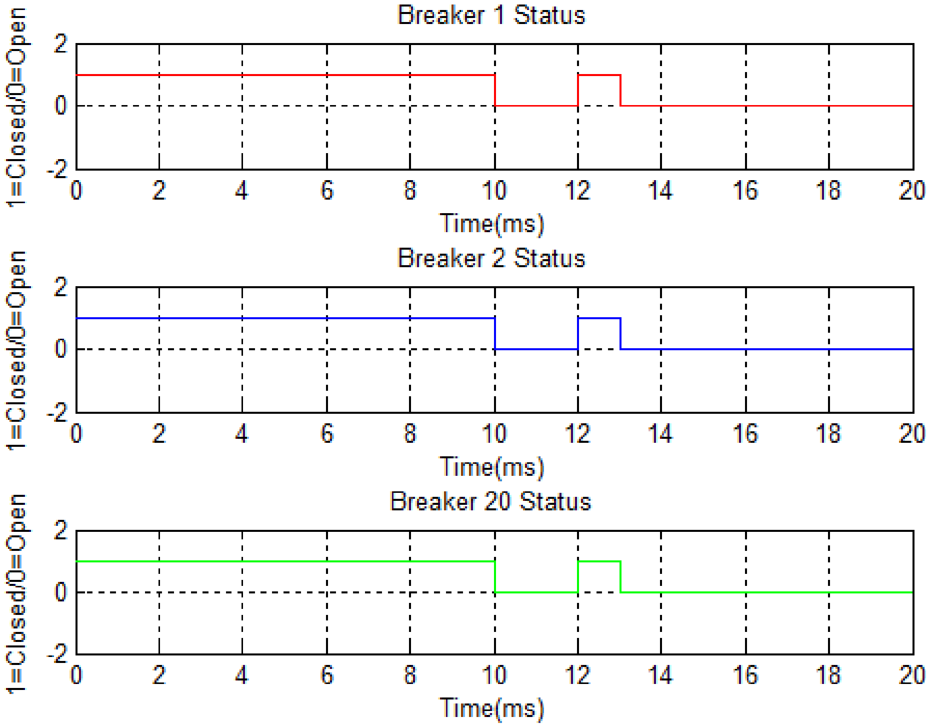

Figure 5.17: Zone 1 Breaker Status During a Reclose and Lockout Cycle

6. Conclusion and Future Works

With the new interest in green energy, the smart grid and distributed generation microgrids may soon become an integral part of our electric grid. DC microgrids have proven to be a viable competitor to AC migrogrids. Protection of the DC bus is a integral part to the DC microgrid, and must be able to isolate faults with minimal impact to the overall system. It can be seen in Chapter 3 that the current techniques require a complete shutdown of the DC bus. This is not suitable for critical loads.

This research proposes a new fault detection and isolation scheme for low-voltage DC-bus microgrid system. A ring bus based microgrid system was utilized. The proposed protection scheme consists of zone IED's which are capable of detecting abnormal fault current in the ring bus segment and isolating the segment to avoid the entire system shutdown. The ring bus was separated into overlapping zones with IED's monitoring each zone has been proposed. The ring bus allows multiple paths for power to flow when a section has been isolated. Overlapping the zones reduced the amount of circuit breakers needed in the microgrid. The use of resistance grounding was utilized in order to limit the fault current, to protect the source converters and also allow the IED enough time to detect and isolate the fault. Successful fault detection and isolation was shown using computer simulations.

Though the fault detection and isolation proves successful for suppressing fault current, locating the faulted zone and isolating the zone for line-to-ground faults, line-to-line faults will still create very large fault current. This is because the fault consists of two sources (positive and negative) and the grouding resistor has no influence on the fault current. Creating an algorithm or control scheme to detect and limit a line-to-line fault is an issue that should be addressed.

Also, when a fault occurs and a source is removed from the microgrid, the remainder of the sources must accommodate the load. Determing a real time load flow control scheme for the microgrid would improve stability in the grid and maximize efficiency from all of the sources.

APPENDIX A. MATLAB Code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%Protection Logic%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all
close all
format short
clc

syms fault;


Imax=400;


SB1=ones(1,20);
SB2=ones(1,20);
SB3=ones(1,20);
SB4=ones(1,20);
SB5=ones(1,20);
SB6=ones(1,20);
SB7=ones(1,20);
SB8=ones(1,20);
SB9=ones(1,20);
SB10=ones(1,20);
SB11=ones(1,20);
SB12=ones(1,20);
SB13=ones(1,20);
SB14=ones(1,20);
SB15=ones(1,20);
SB16=ones(1,20);
SB17=ones(1,20);
SB18=ones(1,20);
SB19=ones(1,20);
SB20=ones(1,20);
SGC=ones(1,20);
SBC=ones(1,20);
SFC=ones(1,20);
SMC=ones(1,20);
SDC=ones(1,20);
SPC=ones(1,20);
SAC=ones(1,20);
STC=ones(1,20);

TB1=zeros(1,20);
TB2=zeros(1,20);
TB3=zeros(1,20);
TB4=zeros(1,20);
TB5=zeros(1,20);
TB6=zeros(1,20);
TB7=zeros(1,20);
TB8=zeros(1,20);
TB9=zeros(1,20);
```

1.pdf

```
TB10=zeros(1,20);
TB11=zeros(1,20);
TB12=zeros(1,20);
TB13=zeros(1,20);
TB14=zeros(1,20);
TB15=zeros(1,20);
TB16=zeros(1,20);
TB17=zeros(1,20);
TB18=zeros(1,20);
TB19=zeros(1,20);
TB20=zeros(1,20);
TGC=zeros(1,20);
TBC=zeros(1,20);
TFC=zeros(1,20);
TMC=zeros(1,20);
TDC=zeros(1,20);
TPC=zeros(1,20);
TAC=zeros(1,20);
TTC=zeros(1,20);

CB1=zeros(1,20);
CB2=zeros(1,20);
CB3=zeros(1,20);
CB4=zeros(1,20);
CB5=zeros(1,20);
CB6=zeros(1,20);
CB7=zeros(1,20);
CB8=zeros(1,20);
CB9=zeros(1,20);
CB10=zeros(1,20);
CB11=zeros(1,20);
CB12=zeros(1,20);
CB13=zeros(1,20);
CB14=zeros(1,20);
CB15=zeros(1,20);
CB16=zeros(1,20);
CB17=zeros(1,20);
CB18=zeros(1,20);
CB19=zeros(1,20);
CB20=zeros(1,20);

Zone_1=zeros(1,20);
Zone_2=zeros(1,20);
Zone_3=zeros(1,20);
Zone_4=zeros(1,20);
Zone_5=zeros(1,20);
Zone_6=zeros(1,20);
Zone_7=zeros(1,20);
Zone_8=zeros(1,20);
Zone_9=zeros(1,20);
Zone_10=zeros(1,20);
Zone_11=zeros(1,20);
```

2.pdf

```
Zone_12=zeros(1,20);
Zone_13=zeros(1,20);
Zone_14=zeros(1,20);
Zone_15=zeros(1,20);
Zone_16=zeros(1,20);
Zone_17=zeros(1,20);
Zone_18=zeros(1,20);
Zone_19=zeros(1,20);
Zone_20=zeros(1,20);


B1F=zeros(1,20);
B2F=zeros(1,20);
B3F=zeros(1,20);
B4F=zeros(1,20);
B5F=zeros(1,20);
B6F=zeros(1,20);
B7F=zeros(1,20);
B8F=zeros(1,20);
B9F=zeros(1,20);
B10F=zeros(1,20);
B11F=zeros(1,20);
B12F=zeros(1,20);
B13F=zeros(1,20);
B14F=zeros(1,20);
B15F=zeros(1,20);
B16F=zeros(1,20);
B17F=zeros(1,20);
B18F=zeros(1,20);
B19F=zeros(1,20);
B20F=zeros(1,20);


Zone_1_RC=zeros(1,20);
Zone_2_RC=zeros(1,20);
Zone_3_RC=zeros(1,20);
Zone_4_RC=zeros(1,20);
Zone_5_RC=zeros(1,20);
Zone_6_RC=zeros(1,20);
Zone_7_RC=zeros(1,20);
Zone_8_RC=zeros(1,20);
Zone_9_RC=zeros(1,20);
Zone_10_RC=zeros(1,20);
Zone_11_RC=zeros(1,20);
Zone_12_RC=zeros(1,20);
Zone_13_RC=zeros(1,20);
Zone_14_RC=zeros(1,20);
Zone_15_RC=zeros(1,20);
Zone_16_RC=zeros(1,20);
Zone_17_RC=zeros(1,20);
Zone_18_RC=zeros(1,20);
Zone_19_RC=zeros(1,20);
```

3.pdf

```
Zone_20_RC=zeros(1,20);

BF_SYM=0;
BF1_SYM=zeros(1,20);
BF2_SYM=zeros(1,20);
BF3_SYM=zeros(1,20);
BF4_SYM=zeros(1,20);
BF5_SYM=zeros(1,20);
BF6_SYM=zeros(1,20);
BF7_SYM=zeros(1,20);
BF8_SYM=zeros(1,20);
BF9_SYM=zeros(1,20);
BF10_SYM=zeros(1,20);
BF11_SYM=zeros(1,20);
BF12_SYM=zeros(1,20);
BF13_SYM=zeros(1,20);
BF14_SYM=zeros(1,20);
BF15_SYM=zeros(1,20);
BF16_SYM=zeros(1,20);
BF17_SYM=zeros(1,20);
BF18_SYM=zeros(1,20);
BF19_SYM=zeros(1,20);
BF20_SYM=zeros(1,20);


cnt=ones(1,20);


for n=1:20

if n<=10

IB1(n)=100;
IB2(n)=200;
IB3(n)=200;
IB4(n)=50;
IB5(n)=150;
IB6(n)=50;
IB7(n)=100;
IB8(n)=50;
IB9(n)=150;
IB10(n)=150;
IB11(n)=50;
IB12(n)=100;
IB13(n)=100;
IB14(n)=50;
IB15(n)=150;
IB16(n)=100;
IB17(n)=50;
IB18(n)=50;
IB19(n)=100;
IB20(n)=100;
```

4.pdf

```
end

if n>10 && BF_SYM==0;
IB1(n)=100;
IB2(n)=150;
IB3(n)=150;
IB4(n)=50;
IB5(n)=100;
IB6(n)=50;
IB7(n)=50;
IB8(n)=50;
IB9(n)=100;
IB10(n)=100;
IB11(n)=50;
IB12(n)=50;
IB13(n)=50;
IB14(n)=50;
IB15(n)=100;
IB16(n)=100;
IB17(n)=0;
IB18(n)=100;
IB19(n)=100;
IB20(n)=100;
end

if n>10 && BF_SYM==1;
IB1(n)=100;
IB2(n)=200;
IB3(n)=200;
IB4(n)=50;
IB5(n)=250;
IB6(n)=50;
IB7(n)=10;
IB8(n)=50;
IB9(n)=60;
IB10(n)=60;
IB11(n)=50;
IB12(n)=10;
IB13(n)=10;
IB14(n)=40;
IB15(n)=50;
IB16(n)=0;
IB17(n)=50;
IB18(n)=50;
IB19(n)=100;
IB20(n)=100;
end
```

5.pdf

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Source Zones%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Zone 5, Micro Turbine Source
if (IB7(n)+IB8(n))~=IB9(n)

    Z5_CHK1=1;

else

    Z5_CHK1=0;
    Zone_5(n)=0;
    Z5(n)=0;

end

if Z5_CHK1==1 && (IB8(n)+IB9(n))~=IB7(n)

    Z5_CHK2=1;

else

    Z5_CHK2=0;
    Zone_5(n)=0;
    Z5(n)=0;
end

if Z5_CHK2==1 && (IB7(n)+IB9(n))~=IB8(n) || IB8(n)>Imax

    Zone_5(n)=1;
    Z5(n)=1;

end

%Zone 9, PV Source
if (IB13(n)+IB14(n))~=IB15(n)

    Z9_CHK1=1;

else

    Z9_CHK1=0;
    Zone_9(n)=0;
    Z9(n)=0;

end

if Z9_CHK1==1 && (IB14(n)+IB15(n))~=IB13(n)

    Z9_CHK2=1;
```

6.pdf

```
else

    Z9_CHK2=0;
    Zone_9(n)=0;
    Z9(n)=0;

end

if Z9_CHK2==1 && (IB13(n)+IB15(n))~=IB14(n) || IB14(n)>Imax

    Zone_9(n)=1;
    Z9(n)=1;

end

%Zone 11, WTG Source

if (IB17(n)+IB18(n))~=IB19(n)

    Z11_CHK1=1;

else

    Z11_CHK1=0;
    Zone_11(n)=0;
    Z11(n)=0;

end

if Z11_CHK1==1 && (IB18(n)+IB19(n))~=IB17(n)

    Z11_CHK2=1;

else

    Z11_CHK2=0;
    Zone_11(n)=0;
    Z11(n)=0;

end

if Z11_CHK2==1 && (IB17(n)+IB19(n))~=IB18(n) || IB18(n)>Imax

    Zone_11(n)=1;
    Z11(n)=1;

end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Load Zones%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

7.pdf

```
%Zone 7, DC Load
if abs((IB10(n)-IB11(n)))~=IB12(n) || IB11(n)>Imax

    Zone_7(n)=1;
    Z7(n)=1;

else
    Zone_7(n)=0;
    Z7(n)=0;
end

%Zone 10, AC Load
if abs((IB15(n)-IB16(n)))~=IB17(n) || IB16(n)>Imax

    Zone_10(n)=1;
    Z10(n)=1;

else

    Zone_10(n)=0;
    Z10(n)=0;

end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%Bi-Directional Zones%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Zone 1, AC Grid Source
Gen=1; %Gen: 0=Charging, 1=Generating
if Gen==1 && ((IB1(n)+IB20(n))~=IB2(n))

    Z1_CHK1=1;

else

    Z1_CHK1=0;
    Zone_1(n)=0;
    Z1(n)=0;
end

if Gen==1 && (Z1_CHK1==1 && (IB1(n)+IB2(n))~=IB20(n))

    Z1_CHK2=1;

else

    Z1_CHK2=0;
    Zone_1(n)=0;
    Z1(n)=0;
end

if Gen==1 && (Z1_CHK2==1 && (IB2(n)+IB20(n))~=IB1(n)) || IB1(n)>Imax
```

8.pdf

```
    Zone_1(n)=1;
    disp('Zone 1');
    Z1(n)=1;

end


if Gen==0 && ((IB20(n)-IB1(n))~=IB2(n))

    Z1_CHK1=1;

elseif Gen==0

    Z1_CHK1=0;
    Zone_1(n)=0;
    Z1(n)=0;
end

if Gen==0 && (Z1_CHK1==1) && ((IB2(n)+IB1(n))~=IB20(n))

    Z1_CHK2=1;

elseif Gen==0

    Z1_CHK2=0;
    Zone_1(n)=0;
    Z1(n)=0;
end

if Gen==0 && (Z1_CHK2==1 && (IB2(n)+IB20(n))~=IB1(n)) || IB1(n)>Imax

    Zone_1(n)=1;
    disp('Zone 1Y');
    Z1(n)=1;

end



%Zone 3, Battery Source/Load
Batt_Stat=0; %Battery Status: 0=Charging, 1=Generating
if Batt_Stat==1 && (IB3(n)+IB4(n))~=IB5(n)

    Z3_CHK1=1;

else

    Z3_CHK1=0;
    Zone_3(n)=0;
    Z3(n)=0;
```

9.pdf

```
end

if Batt_Stat==1 && Z3_CHK1==1 && (IB4(n)+IB5(n))~=IB3(n)

    Z3_CHK2=1;

else

    Z3_CHK2=0;
    Zone_3(n)=0;
    Z3(n)=0;

end

if Batt_Stat==1 && Z3_CHK2==1 && (IB3(n)+IB5(n))~=IB4(n) || IB4(n)>Imax

        Zone_3(n)=1;
        Z3(n)=1;

end


if Batt_Stat==0 && (IB3(n)-IB4(n))~=IB5(n)

    Z3_CHK1=1;

elseif Batt_Stat==0

    Z3_CHK1=0;
    Zone_3(n)=0;
    Z3(n)=0;

end

if Batt_Stat==0 && Z3_CHK1==1 && (IB5(n)-IB4(n))~=IB3(n)

    Z3_CHK2=1;

elseif Batt_Stat==0

    Z3_CHK2=0;
    Zone_3(n)=0;
    Z3(n)=0;

end

if Batt_Stat==0 && Z3_CHK2==1 && (IB3(n)+IB5(n))~=IB4(n) || IB4(n)>Imax

        Zone_3(n)=1;
        Z3(n)=1;

end
```

10.pdf

```
%Zone 4, Flywheel Source/Load
Flywheel_Stat=1; %Flywheel Status: 0=Charging, 1=Generating
if Flywheel_Stat==1 && (IB5(n)+IB6(n))~=IB7(n)

   Z4_CHK1=1;

else

    Z4_CHK1=0;
    Zone_4(n)=0;
    Z4(n)=0;

end

if Flywheel_Stat==1 && Z4_CHK1==1 && (IB6(n)+IB7(n))~=IB5(n)

   Z4_CHK2=1;

else

    Z4_CHK2=0;
    Zone_4(n)=0;
    Z4(n)=0;

end

if Flywheel_Stat==1 && Z4_CHK2==1 && (IB5(n)+IB7(n))~=IB6(n) || IB6(n)>Imax

    Zone_4(n)=1;
    Z4(n)=1;

end



if Flywheel_Stat==0 && (IB5(n)-IB6(n))~=IB7(n)

    Z4_CHK1=1;

elseif Flywheel_Stat==0

    Z4_CHK1=0;
    Zone_4(n)=0;
    Z4(n)=0;

end

if Flywheel_Stat==0 && Z4_CHK2==1 && (IB7(n)-IB6(n))~=IB5(n)

    Z4_CHK2=1;
```

11.pdf

```
elseif Flywheel_Stat==0

    Z4_CHK2=0;
    Zone_4(n)=0;
    Z4(n)=0;

end

if Flywheel_Stat==0 && Z4_CHK2==1 && (IB5(n)+IB7(n))~=IB6(n) || IB6(n)>Imax

    Zone_4(n)=1;
    Z4(n)=1;


end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Link Zones%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if IB2(n)~=IB3(n)

    Zone_2(n)=1;
    Z2(n)=1;

else

    Zone_2(n)=0;
    Z2(n)=0;

end

if IB9(n)~=IB10(n)

    Zone_6(n)=1;
    Z6(n)=1;

else

   Zone_6(n)=0;
   Z6(n)=0;

end

if IB12(n)~=IB13(n)

    Zone_8(n)=1;
    Z8(n)=1;

else

    Zone_8(n)=0;
    Z8(n)=0;
```

12.pdf

```
end

if IB19(n)~=IB20(n)

    Zone_12(n)=1;
    Z12(n)=1;

else

    Zone_12(n)=0;
    Z12(n)=1;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 1%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_1(n)==1 && Z1T(n-1)==0

SB1(n)=0;
SB2(n)=0;
SB20(n)=0;
TB1(n)=1;
TB2(n)=1;
TB20(n)=1;
disp('gg')

end

if Z1(n)==1

    Z1T(n)=1;

else

    Z1T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 2%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_2(n)==1 && Z2T(n-1)==0

SB2(n)=0;
SB3(n)=0;
TB2(n)=1;
TB3(n)=1;


end

if Z2(n)==1
```

13.pdf

```
    Z2T(n)=1;

else

    Z2T(n)=0;

end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 3%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_3(n)==1 && Z3T(n-1)==0

SB3(n)=0;
SB4(n)=0;
SB5(n)=0;
TB3(n)=1;
TB4(n)=1;
TB5(n)=1;

end

if Z3(n)==1

    Z3T(n)=1;

else

    Z3T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 4%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_4(n)==1 && Z4T(n-1)==0

SB5(n)=0;
SB6(n)=0;
SB7(n)=0;
TB5(n)=1;
TB6(n)=1;
TB7(n)=1;

end

if Z4(n)==1

    Z4T(n)=1;

else

    Z4T(n)=0;

end
```

14.pdf

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 5%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_5(n)==1 && Z5T(n-1)==0

SB7(n)=0;
SB8(n)=0;
SB9(n)=0;
TB7(n)=1;
TB8(n)=1;
TB9(n)=1;

end

if Z5(n)==1

    Z5T(n)=1;

else

    Z5T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 6%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_6(n)==1 && Z6T(n-1)==0

SB9(n)=0;
SB10(n)=0;
TB9(n)=1;
TB10(n)=1;

end

if Z6(n)==1

    Z6T(n)=1;

else

    Z6T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 7%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_7(n)==1 && Z7T(n-1)==0

SB10(n)=0;
SB11(n)=0;
SB12(n)=0;
TB10(n)=1;
TB11(n)=1;
TB12(n)=1;
```

15.pdf

```
end

if Z7(n)==1

    Z7T(n)=1;

else

    Z7T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 8%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_8(n)==1 && Z8T(n-1)==0

SB12(n)=0;
SB13(n)=0;
TB12(n)=1;
TB13(n)=1;

end

if Z8(n)==1

    Z8T(n)=1;

else

    Z8T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 9%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_9(n)==1 && Z9T(n-1)==0

SB13(n)=0;
SB14(n)=0;
SB15(n)=0;
TB13(n)=1;
TB14(n)=1;
TB15(n)=1;

end

if Z9(n)==1

    Z9T(n)=1;

else

    Z9T(n)=0;
```

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```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 10%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_10(n)==1 && Z10T(n-1)==0

SB15(n)=0;
SB16(n)=0;
SB17(n)=0;
TB15(n)=1;
TB16(n)=1;
TB17(n)=1;

end

if Z10(n)==1

    Z10T(n)=1;

else

    Z10T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 11%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_11(n)==1 && Z11T(n-1)==0

SB17(n)=0;
SB18(n)=0;
SB19(n)=0;
TB17(n)=1;
TB18(n)=1;
TB19(n)=1;

end

if Z11(n)==1

    Z11T(n)=1;

else

    Z11T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 12%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_12(n)==1 && Z12T(n-1)==0

SB19(n)=0;
SB20(n)=0;
```

17.pdf

```
TB19(n)=1;
TB20(n)=1;

end

if Z12(n)==1

    Z12T(n)=1;

else

    Z12T(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 1 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_1(n)==1

    if BF1_SYM(n)==1

       SB1(n)=1;

    else

        SB1(n)=0;

    end


    if BF2_SYM(n)==1

       SB2(n)=1;

    else

        SB2(n)=0;

    end


    if BF20_SYM(n)==1

       SB20(n)=1;

    else

        SB20(n)=0;

    end
```

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```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 2 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_2(n)==1

    if BF2_SYM(n)==1

       SB2(n)=1;

    else

        SB2(n)=0;

    end


    if BF3_SYM(n)==1

       SB3(n)=1;

    else

        SB3(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 3 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_3(n)==1

    if BF3_SYM(n)==1

       SB3(n)=1;

    else

        SB3(n)=0;

    end


    if BF4_SYM(n)==1

       SB4(n)=1;

    else

        SB4(n)=0;

    end
```

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```
    if BF5_SYM(n)==1

       SB5(n)=1;

    else

        SB5(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 4 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_4(n)==1

    if BF5_SYM(n)==1

       SB5(n)=1;

    else

        SB5(n)=0;

    end


    if BF6_SYM(n)==1

       SB6(n)=1;

    else

        SB6(n)=0;

    end


    if BF7_SYM(n)==1

       SB7(n)=1;

    else

        SB7(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 5 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_5(n)==1
```

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```
    if BF7_SYM(n)==1

       SB7(n)=1;

    else

        SB7(n)=0;

    end


    if BF8_SYM(n)==1

       SB8(n)=1;

    else

        SB8(n)=0;

    end

   if BF9_SYM(n)==1

       SB9(n)=1;

    else

       SB9(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 6 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_6(n)==1

    if BF9_SYM(n)==1

       SB9(n)=1;

    else

        SB9(n)=0;

    end


    if BF10_SYM(n)==1

       SB10(n)=1;
```

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```
    else

        SB10(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 7 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_7(n)==1

    if BF10_SYM(n)==1

       SB10(n)=1;

    else

        SB10(n)=0;

    end


    if BF11_SYM(n)==1

       SB11(n)=1;

    else

        SB11(n)=0;

    end


    if BF12_SYM(n)==1

       SB12(n)=1;

    else

        SB12(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 8 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_8(n)==1

    if BF12_SYM(n)==1

       SB12(n)=1;
```

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```
    else

        SB12(n)=0;

    end


    if BF13_SYM(n)==1

       SB13(n)=1;

    else

        SB13(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 9 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_9(n)==1

    if BF13_SYM(n)==1

       SB13(n)=1;

    else

        SB13(n)=0;

    end

    if BF14_SYM(n)==1

       SB14(n)=1;

    else

        SB14(n)=0;

    end

    if BF15_SYM(n)==1

       SB15(n)=1;

    else

        SB15(n)=0;

    end
```

23.pdf

```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 10 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_10(n)==1

    if BF15_SYM(n)==1

       SB15(n)=1;

    else

        SB15(n)=0;

    end


    if BF16_SYM(n)==1

       SB16(n)=1;

    else

        SB16(n)=0;

    end

    if BF17_SYM(n)==1

       SB17(n)=1;

    else

        SB17(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 11 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_11(n)==1

    if BF17_SYM(n)==1

       SB17(n)=1;

    else

        SB17(n)=0;

    end
```

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```
    if BF18_SYM(n)==1

       SB18(n)=1;

    else

        SB18(n)=0;

    end

    if BF19_SYM(n)==1

       SB19(n)=1;

    else

        SB19(n)=0;

    end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 12 BF_SYM%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_12(n)==1

    if BF19_SYM(n)==1

       SB19(n)=1;

    else

        SB19(n)=0;

    end

    if BF20_SYM(n)==1

       SB20(n)=1;

    else

        SB20(n)=0;

    end

end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%Breaker Fail Check%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_1(n)==1,
```

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```
    if SB1(n)==1 && IB1~=0

        B1F(n)=1;

    end

  if SB2(n)==1 && IB2~=0 ,

        B2F(n)=1;
  end

  if SB20(n)==1 && IB20~=0

     B20F(n)=1;

  end

  if SB1(n)==0 && SB2(n)==0 && SB20(n)==0 && (IB1~=0 || IB2~=0 ||IB20~=0)

    B1F(n)=1;
    B2F(n)=1;
    B20F(n)=1;

  end


end

if Zone_2(n)==1,

    if SB2(n)==1 && IB2~=0,

         B2F(n)=1;

     end

     if SB3(n)==1 && IB3~=0,

         B3F(n)=1;

     end

  if SB2(n)==0 && SB2(n)==0 && SB20(n)==0 && (IB2~=0 || IB3~=0)

    B2F(n)=1;
    B3F(n)=1;

  end

end
```

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```
if Zone_3(n)==1,

     if SB3(n)==1 && IB3~=0,

        B3F(n)=1;

     end

     if SB4(n)==1 && IB4~=0 ,

        B4F(n)=1;

     end

     if SB5(n)==1 && IB5~=0,

        B5F(n)=1;

     end


  if SB3(n)==0 && SB4(n)==0 && SB5(n)==0 && (IB3~=0 || IB4~=0 ||IB5~=0)

    B3F(n)=1;
    B4F(n)=1;
    B5F(n)=1;

  end

end

if Zone_4(n)==1,


    if SB5(n)==1 && IB5~=0,

       B5F(n)=1;

    end

    if SB6(n)==1 && IB6~=0,

       B6F(n)=1;

    end

    if SB7(n)==1 && IB7~=0,

       B7F(n)=1;

    end
```

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```
  if SB5(n)==0 && SB6(n)==0 && SB7(n)==0 && (IB5~=0 || IB6~=0 ||IB7~=0)

    B5F(n)=1;
    B6F(n)=1;
    B7F(n)=1;

  end

end

if Zone_5(n)==1,

    if SB7(n)==1 && IB7~=0,

       B7F(n)=1;

    end

    if SB8(n)==1 && IB8~=0,

        B8F(n)=1;

    end

    if SB9(n)==1 && IB9~=0,

       B9F(n)=1;

    end


  if SB7(n)==0 && SB8(n)==0 && SB9(n)==0 && (IB7~=0 || IB8~=0 ||IB9~=0)

    B7F(n)=1;
    B8F(n)=1;
    B9F(n)=1;

  end

end

if Zone_6(n)==1,

    pause(0.5)

    if SB9(n)==1 && IB9~=0,

      B9F(n)=1;

    end
```

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```
    if SB10(n)==1 && IB10~=0,

      B10F=1;

    end


  if SB9(n)==0 && SB10(n)==0 && (IB9~=0 || IB10~=0)

    B9F(n)=1;
    B10F(n)=1;

  end

end

if Zone_7==1,

    if SB10(n)==1 && IB10~=0,

      B10F(n)=1;

    end

    if SB11(n)==1 && IB11~=0,

        B11F(n)=1;

    end

    if SB12(n)==1 && IB12~=0,

        B12F(n)=1;

    end

if SB10(n)==0 && SB11(n)==0 && SB12(n)==0 && (IB10~=0 || IB11~=0 ||IB12~=0)

    B10F(n)=1;
    B11F(n)=1;
    B12F(n)=1;

end
end

if Zone_8(n)==1,

    if SB12(n)==1 && IB12~=0,

      B12F(n)=1;

    end
```

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```
    if SB13(n)==1 && IB13~=0,

      B13F(n)=1;

    end

    if SB12(n)==0 && SB13(n)==0 && (IB12~=0 || IB13~=0)

    B12F(n)=1;
    B13F(n)=1;

    end
end

if Zone_9(n)==1,

    if SB13(n)==1 && IB13~=0,

     B13F=1;

    end

    if SB14(n)==1 && IB14~=0,

      B14F(n)=1;

    end

    if SB15(n)==1 && IB15~=0,

      B15F(n)=1;

    end

if SB13(n)==0 && SB14(n)==0 && SB15(n)==0 && (IB13~=0 || IB14~=0 ||IB15~=0)

    B13F(n)=1;
    B14F(n)=1;
    B15F(n)=1;

end
end

if Zone_10(n)==1,

    if SB15(n)==1 && IB15~=0,

      B15F(n)=1;

    end
```

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```
    if SB16(n)==1 && IB16~=0,

      B16F(n)=1;

    end

    if SB17(n)==1 && IB17~=0,

      B17F(n)=1;

    end

if SB15(n)==0 && SB16(n)==0 && SB17(n)==0 && (IB15~=0 || IB16~=0 ||IB17~=0)

    B15F(n)=1;
    B16F(n)=1;
    B17F(n)=1;

end

end

if Zone_11(n)==1,

    if SB17(n)==1 && IB17~=0,

      B17F(n)=1;

    end

    if SB18(n)==1 && IB18~=0,

      B18F(n)=1;

    end

    if SB19(n)==1 && IB19~=0,

      B19F(n)=1;

    end

if SB17(n)==0 && SB18(n)==0 && SB19(n)==0 && (IB17~=0 || IB18~=0 ||IB19~=0)

    B17F(n)=1;
    B18F(n)=1;
    B19F(n)=1;

end
end

if Zone_12(n)==1,
```

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```
    pause(0.5)

    if SB19(n)==1 && IB19~=0,

      B19F(n)=1;

    end

   if SB20(n)==1 && IB20~=0

      B20F(n)=1;

   end

if SB19(n)==0 && SB20(n)==0 && (IB19~=0 || IB20~=0)

    B19F(n)=1;
    B20F(n)=1;

end

end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 1%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B1F(n)==1

    SGC(n+1)=0;
    disp('Breaker 1 Has Failed!')
    B1FT(n)=1;

else

    B1FT(n)=0;

end

if B1FT(n)==1 && B1FTB(n-1)==0

    TGC(n+1)=1;

end

if B1FT(n)==1

   B1FTB(n)=1;

else
```

32.pdf

```
    B1FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 2%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B2F(n)==1

    disp('Breaker 2 Has Failed!')
    SB1(n+1)=0;
    SB3(n+1)=0;
    SB20(n+1)=0;
    B2FT(n)=1;

else

    B2FT(n)=0;

end

if B2FT(n)==1 && B2FTB(n-1)==0

    TB1(n+1)=1;
    TB3(n+1)=1;
    TB20(n+1)=1;

end

if B2FT(n)==1

   B2FTB(n)=1;

else

    B2FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 3%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B3F(n)==1

    disp('Breaker 3 Has Failed!')
    SB2(n+1)=0;
    SB4(n+1)=0;
    SB5(n+1)=0;
    B3FT(n)=1;


else

    B3FT(n)=0;
```

33.pdf

```
end

if B3FT(n)==1 && B3FTB(n-1)==0

    TB2(n+1)=1;
    TB3(n+1)=1;
    TB4(n+1)=1;

end

if B3FT(n)==1

   B3FTB(n)=1;

else

    B3FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 4%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B4F(n)==1

    disp('Breaker 4 Has Failed!')
    SB3(n+1)=0;
    SB4(n+1)=0;
    SBC(n+1)=0;
    B4FT(n)=1;

else

    B4FT(n)=0;

end

if B4FT(n)==1 && B4FTB(n-1)==0

    TB3(n+1)=1;
    TB4(n+1)=1;
    TBC(n+1)=1;

end

if B4FT(n)==1

   B4FTB(n)=1;

else

    B4FTB(n)=0;

end
```

34.pdf

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 5%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B5F(n)==1

    disp('Breaker 5 Has Failed!')
    SB3(n+1)=0;
    SB4(n+1)=0;
    SB6(n+1)=0;
    SB7(n+1)=0;
    B5FT(n)=1;
    CKB5(n)=1;

else

    B5FT(n)=0;


end

if B5FT(n)==1 && B5FTB(n-1)==0

    TB3(n+1)=1;
    TB4(n+1)=1;
    TB6(n+1)=1;
    TB7(n+1)=1;

end

if B5FT(n)==1

   B5FTB(n)=1;

else

    B5FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 6%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B6F(n)==1

    disp('Breaker 6 Has Failed!')
    SB5(n+1)=0;
    SFC(n+1)=0;
    SB7(n+1)=0;
    B6FT(n)=1;

else

    B6FT(n)=0;

end
```

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```
if B6FT(n)==1 && B6FTB(n-1)==0

    TB5(n+1)=1;
    TFC(n+1)=1;
    TB7(n+1)=1;

end

if B6FT(n)==1

   B6FTB(n)=1;

else

    B6FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 7%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B7F(n)==1

    disp('Breaker 7 Has Failed!')
    SB5(n+1)=0;
    SB6(n+1)=0;
    SB8(n+1)=0;
    SB9(n+1)=0;
    B7FT(n)=1;

else

    B7FT(n)=0;

end

if B7FT(n)==1 && B7FTB(n-1)==0

    TB5(n+1)=1;
    TB6(n+1)=1;
    TB8(n+1)=1;
    TB9(n+1)=1;

end

if B7FT(n)==1

   B7FTB(n)=1;

else

    B7FTB(n)=0;
```

36.pdf

```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 8%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B8F(n)==1

    disp('Breaker 8 Has Failed!')
    SB7(n+1)=0;
    SMC(n+1)=0;
    SB9(n+1)=0;
    B8FT(n)=1;

else

    B8FT(n)=0;

end

if B8FT(n)==1 && B8FTB(n-1)==0

    TB7(n+1)=1;
    TMC(n+1)=1;
    TB9(n+1)=1;

end

if B8FT(n)==1

   B8FTB(n)=1;

else

    B8FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 9%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B9F(n)==1

    disp('Breaker 9 Has Failed!')
    SB7(n+1)=0;
    SB8(n+1)=0;
    SB10(n+1)=0;
    B9FT(n)=1;

else

    B9FT(n)=0;

end

if B9FT(n)==1 && B9FTB(n-1)==0
```

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```
    TB7(n+1)=1;
    TB8(n+1)=1;
    TB10(n+1)=1;

end

if B9FT(n)==1

   B9FTB(n)=1;

else

    B9FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 10%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B10F(n)==1

    disp('Breaker 10 Has Failed!')
    SB9(n+1)=0;
    SB11(n+1)=0;
    SB12(n+1)=0;
    B10FT(n)=1;

else

    B10FT(n)=0;

end

if B10FT(n)==1 && B10FTB(n-1)==0

    TB9(n+1)=1;
    TB11(n+1)=1;
    TB12(n+1)=1;

end

if B10FT(n)==1

   B10FTB(n)=1;

else

    B10FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 11%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B11F(n)==1
```

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```
    disp('Breaker 11 Has Failed!')
    SB10(n+1)=0;
    SDC(n+1)=0;
    SB12(n+1)=0;
    B11FT(n)=1;

else

    B11FT(n)=0;

end

if B11FT(n)==1 && B11FTB(n-1)==0

    TB10(n+1)=1;
    TDC(n+1)=1;
    TB12(n+1)=1;

end

if B11FT(n)==1

   B11FTB(n)=1;

else

    B11FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 12%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B12F(n)==1

    disp('Breaker 12 Has Failed!')
    SB10(n+1)=0;
    SB11(n+1)=0;
    SB13(n+1)=0;
    B12FT(n)=1;

else

    B12FT(n)=0;

end

if B12FT(n)==1 && B12FTB(n-1)==0

    TB10(n+1)=1;
    TB11(n+1)=1;
    TB13(n+1)=1;

end
```

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```
if B12FT(n)==1

   B12FTB(n)=1;

else

    B12FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 13%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B13F(n)==1

    disp('Breaker 13 Has Failed!')
    SB12(n+1)=0;
    SB14(n+1)=0;
    SB15(n+1)=0;
    B13FT(n)=1;

else

    B13FT(n)=0;

end

if B13FT(n)==1 && B13FTB(n-1)==0

    TB12(n+1)=1;
    TB14(n+1)=1;
    TB15(n+1)=1;

end

if B13FT(n)==1

    B13FTB(n)=1;

else

    B13FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 14%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B14F(n)==1

    disp('Breaker 14 Has Failed!')
    SB13(n+1)=0;
    SPC(n+1)=0;
    SB15(n+1)=0;
    B14FT(n)=1;
```

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```
else

    B14FT(n)=0;

end

if B14FT(n)==1 && B14FTB(n-1)==0

    TB13(n+1)=1;
    TBC(n+1)=1;
    TB15(n+1)=1;

end

if B14FT(n)==1

   B14FTB(n)=1;

else

    B14FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 15%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B15F(n)==1

    disp('Breaker 15 Has Failed!')
    SB13(n+1)=0;
    SB14(n+1)=0;
    SB16(n+1)=0;
    SB17(n+1)=0;
    B15FT(n)=1;

else

    B15FT(n)=0;

end

if B15FT(n)==1 && B15FTB(n-1)==0

    TB13(n+1)=1;
    TB14(n+1)=1;
    TB16(n+1)=1;
    TB17(n+1)=1;

end

if B15FT(n)==1
```

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```
   B15FTB(n)=1;

else

    B15FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 16%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B16F(n)==1

    disp('Breaker 16 Has Failed!')
    SB15(n+1)=0;
    SAC(n+1)=0;
    SB17(n+1)=0;
    B16FT(n)=1;

else

    B16FT(n)=0;

end

if B16FT(n)==1 && B16FTB(n-1)==0

    TB15(n+1)=1;
    TAC(n+1)=1;
    TB17(n+1)=1;

end

if B16FT(n)==1

   B16FTB(n)=1;

else

    B16FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 17%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B17F(n)==1

    disp('Breaker 17 Has Failed!')
    SB15(n+1)=0;
    SB16(n+1)=0;
    SB18(n+1)=0;
    SB19(n+1)=0;
    B17FT(n)=1;

else
```

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```
    B17FT(n)=0;

end

if B17FT(n)==1 && B17FTB(n-1)==0

    TB15(n+1)=1;
    TB16(n+1)=1;
    TB18(n+1)=1;
    TB19(n+1)=1;

end

if B17FT(n)==1

   B17FTB(n)=1;

else

    B17FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 18%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B18F(n)==1

    disp('Breaker 18 Has Failed!')
    SB17(n+1)=0;
    STC(n+1)=0;
    SB19(n+1)=0;
    B18FT(n)=1;

else

    B18FT(n)=0;

end

if B18FT(n)==1 && B18FTB(n-1)==0

    TB17(n+1)=1;
    TTC(n+1)=1;
    TB19(n+1)=1;

end

if B18FT(n)==1

   B18FTB(n)=1;

else
```

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```
    B18FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 19%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B19F(n)==1

    disp('Breaker 19 Has Failed!')
    SB17(n+1)=0;
    SB18(n+1)=0;
    SB20(n+1)=0;
    B19FT(n)=1;

else

    B19FT(n)=0;

end

if B19FT(n)==1 && B19FTB(n-1)==0

    TB17(n+1)=1;
    TB18(n+1)=1;
    TB20(n+1)=1;

end

if B19FT(n)==1

   B19FTB(n)=1;

else

    B19FTB(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Breaker 20%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if B20F(n)==1

    disp('Breaker 20 Has Failed!')
    SB1(n+1)=0;
    SB2(n+1)=0;
    SB19(n+1)=0;
    B20FT(n)=1;

else

    B20FT(n)=0;

end
```

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```
if B20FT(n)==1 && B20FTB(n-1)==0

    TB1(n+1)=1;
    TB2(n+1)=1;
    TB19(n+1)=1;

end

if B20FT(n)==1

   B20FTB(n)=1;

else

    B20FTB(n)=0;

end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%Reclosing Cycle%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

if n>10 && B1F(n)==0 && B2F(n)==0 && B20F(n)==0

    IB1(n)=0;
    IB2(n)=0;
    IB20(n)=0;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 1%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_1(n)==1 && Zone_1_RC(n)==0 && IB1(n)==0 && IB2(n)==0 &&....
    IB20(n)==0 && B1F(n)==0 && B2F(n)==0 && B20F(n)==0

 Zone_1_RC(n)=1;
 Z1RC(n)=1;

else

  Z1RC(n)=0;

end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone 2%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_2(n)==1 && Zone_2_RC(n)==0 && IB2(n)==0 && IB3(n)==0....
    && B2F(n)==0 && B3F(n)==0

 Zone_2_RC(n)=1;

 Z2RC(n)=1;
```

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```
else

 Z2RC(n)=0;

end


if Zone_3(n)==1 && Zone_3_RC(n)==0 && IB3(n)==0 && IB4(n)==0 &&....
    IB5(n)==0 && B3F(n)==0 && B4F(n)==0 && B5F(n)==0


 Zone_3_RC(n)=1;

 Z3RC(n)=1;

else

 Z3RC(n)=0;
end

if Zone_4(n)==1 && Zone_4_RC(n)==0 && IB5(n)==0 && IB6(n)==0....
        && IB7(n)==0 && B5F(n)==0 && B6F(n)==0 && B7F(n)==0

 Zone_4_RC(n)=1;

 Z4RC(n)=1;

else

 Z4RC(n)=0;

end

if Zone_5(n)==1 && Zone_5_RC(n)==0 && IB7(n)==0 && IB8(n)==0....
        && IB9(n)==0 && B7F(n)==0 && B8F(n)==0 && B9F(n)==0

 Zone_5_RC(n)=1;

 Z5RC(n)=1;

else

 Z5RC(n)=0;

end

if Zone_6(n)==1 && Zone_6_RC(n)==0 && IB9(n)==0 && IB10(n)==0....
        && B9F(n)==0 && B10F(n)==0

 Zone_6_RC(n)=1;
```

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```
 Z6RC(n)=1;

else

 Z6RC(n)=0;

end

if Zone_7(n)==1 && Zone_7_RC(n)==0 && IB10(n)==0 && IB11(n)==0....
        && IB12(n)==0 && B10F(n)==0 && B11F(n)==0 && B12F(n)==0

 Zone_7_RC(n)=1;

 Z7RC(n)=1;

else

 Z7RC(n)=0;

end

if Zone_8(n)==1 && Zone_8_RC(n)==0 && IB12(n)==0 && IB13(n)==0....
        && B12F(n)==0 && B13F(n)==0

Zone_8_RC(n)=1;

Z8RC(n)=1;

else

Z8RC(n)=0;

end

if Zone_9(n)==1 && Zone_9_RC(n)==1 && IB13(n)==0 && IB14(n)==0....
        && IB15(n)==0 && B13F(n)==0 && B15F(n)==0 && B15F(n)==0

Zone_9_RC(n)=1;


Z9RC(n)=1;

else

Z9RC(n)=0;

end

if Zone_10(n)==1 && Zone_10_RC(n)==0 && IB15(n)==0 && IB16(n)==0....
        && IB17(n)==0 && B15F==0 && B16F==0 && B17F==0

 Zone_10_RC(n)=1;
```

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```
Z10RC(n)=1;

else

Z10RC(n)=0;

end

if Zone_11(n)==1 && Zone_11_RC(n)==1 && IB17(n)==0 && IB18(n)==0....
        && IB19(n)==0 && B17F(n)==0 && B18F(n)==0 && B19F(n)==0

 Zone_11_RC(n)=1;

Z11RC(n)=1;

else

Z11RC(n)=0;

end

if Zone_12(n)==1 && Zone_12_RC(n)==1 && IB19(n)==0 && IB20(n)==0....
        && B19F(n)==0 && B20F(n)==0

 Zone_12_RC(n)=1;

Z12RC(n)=1;

else

Z12RC(n)=0;


end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone1 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_1_RC(n)==1 && Z1RCB(n-1)==0

    disp('Attempting Zone 1 Reclose');

    CB1(n+1)=1;
    CB2(n+1)=1;
    CB20(n+1)=1;

end

if CB1(n)==1 || CB2(n)==1 || CB20(n)==1

    SB1(n)=1;
    SB2(n)=1;
    SB20(n)=1;
```

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```
end

if Z1RC(n)==1

   Z1RCB(n)=1;

else

    Z1RCB(n)=0;

end

if Zone_1_RC(n)==1 && Z1RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 1 Locked Out');

    SB1(n+2)=0;
    SB2(n+2)=0;
    SB20(n+2)=0;
    RTZ1(n)=1;

else

    RTZ1(n)=0;

end

if RTZ1(n)==1 && RTZ1B(n-1)==0;

    TB1(n+3)=1;
    TB2(n+3)=1;
    TB20(n+3)=1;


end

if RTZ1(n)==1

   RTZ1B(n)=1;

else

    RTZ1B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone2 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_2_RC(n)==1 && Z2RCB(n-1)==0

    disp('Attempting Zone 2 Reclose');
```

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```
    CB2(n+1)=1;
    CB3(n+1)=1;

end

if CB2(n)==1 || CB3(n)==1

    SB2(n)=1;
    SB3(n)=1;

end

if Z2RC(n)==1

   Z2RCB(n)=1;

else

    Z2RCB(n)=0;

end

if Zone_2_RC(n)==1 && Z2RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 2 Locked Out');

    SB2(n+2)=0;
    SB3(n+2)=0;
    RTZ2(n)=1;

else

    RTZ2(n)=0;

end

if RTZ2(n)==1 && RTZ2B(n-1)==0;

    TB2(n+2)=1;
    TB3(n+2)=1;

end

if RTZ2(n)==1

   RTZ2B(n)=1;

else

    RTZ2B(n)=0;
```

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```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone3 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_3_RC(n)==1 && Z3RCB(n-1)==0

    disp('Attempting Zone 3 Reclose');

    CB3(n+1)=1;
    CB4(n+1)=1;
    CB5(n+1)=1;


end

if CB3(n)==1 || CB4(n)==1 || CB5(n)==1

    SB3(n)=1;
    SB4(n)=1;
    SB5(n)=1;

end

if Z3RC(n)==1

   Z3RCB(n)=1;

else

    Z3RCB(n)=0;

end

if Zone_3_RC(n)==1 && Z3RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 3 Locked Out');

    SB3(n+2)=0;
    SB4(n+2)=0;
    SB5(n+2)=0;
    RTZ3(n)=1;

else

    RTZ3(n)=0;

end

if RTZ3(n)==1 && RTZ3B(n-1)==0;

    TB3(n+2)=1;
```

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```
    TB4(n+2)=1;
    TB5(n+2)=1;

end

if RTZ3(n)==1

   RTZ3B(n)=1;

else

    RTZ3B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone4 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_4_RC(n)==1 && Z4RCB(n-1)==0

    disp('Attempting Zone 4 Reclose');

    CB5(n+1)=1;
    CB6(n+1)=1;
    CB7(n+1)=1;


end

if CB5(n)==1 || CB6(n)==1 || CB7(n)==1

    SB5(n)=1;
    SB6(n)=1;
    SB7(n)=1;

end

if Z4RC(n)==1

   Z4RCB(n)=1;

else

    Z4RCB(n)=0;

end

if Zone_4_RC(n)==1 && Z4RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 4 Locked Out');

    SB5(n+2)=0;
    SB6(n+2)=0;
```

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```
    SB7(n+2)=0;
    RTZ4(n)=1;

else

    RTZ4(n)=0;

end

if RTZ4(n)==1 && RTZ4B(n-1)==0;

    TB5(n+2)=1;
    TB6(n+2)=1;
    TB7(n+2)=1;

end

if RTZ4(n)==1

   RTZ4B(n)=1;

else

    RTZ4B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone5 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_5_RC(n)==1 && Z5RCB(n-1)==0

    disp('Attempting Zone 5 Reclose');

    CB7(n+1)=1;
    CB8(n+1)=1;
    CB9(n+1)=1;


end

if CB7(n)==1 || CB8(n)==1 || CB9(n)==1

    SB7(n)=1;
    SB8(n)=1;
    SB9(n)=1;

end

if Z5RC(n)==1

   Z5RCB(n)=1;

else
```

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```
    Z5RCB(n)=0;

end

if Zone_5_RC(n)==1 && Z5RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 5 Locked Out');

    SB7(n+2)=0;
    SB8(n+2)=0;
    SB9(n+2)=0;
    RTZ5(n)=1;

else

    RTZ5(n)=0;

end

if RTZ5(n)==1 && RTZ5B(n-1)==0;

    TB7(n+2)=1;
    TB8(n+2)=1;
    TB9(n+2)=1;

end

if RTZ5(n)==1

   RTZ5B(n)=1;

else

    RTZ5B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone6 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_6_RC(n)==1 && Z6RCB(n-1)==0

    disp('Attempting Zone 6 Reclose');

    CB9(n+1)=1;
    CB10(n+1)=1;

end

if CB9(n)==1 || CB10(n)==1

    SB9(n)=1;
```

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```
    SB10(n)=1;

end

if Z6RC(n)==1

   Z6RCB(n)=1;

else

    Z6RCB(n)=0;

end

if Zone_6_RC(n)==1 && Z6RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 6 Locked Out');

    SB9(n+2)=0;
    SB10(n+2)=0;
    RTZ6(n)=1;

else

    RTZ6(n)=0;

end

if RTZ6(n)==1 && RTZ6B(n-1)==0;

    TB9(n+2)=1;
    TB10(n+2)=1;

end

if RTZ6(n)==1

   RTZ6B(n)=1;

else

    RTZ6B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone7 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_7_RC(n)==1 && Z7RCB(n-1)==0

    disp('Attempting Zone 7 Reclose');

    CB10(n+1)=1;
```

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```
            CB11(n+1)=1;
            CB12(n+1)=1;


        end

        if CB10(n)==1 || CB11(n)==1 || CB12(n)==1

            SB10(n)=1;
            SB11(n)=1;
            SB12(n)=1;

        end

        if Z7RC(n)==1

           Z7RCB(n)=1;

        else

            Z7RCB(n)=0;

        end

        if Zone_7_RC(n)==1 && Z7RCB(n)==1

            disp('Reclose Failed');
            disp('Zone 7 Locked Out');

            SB10(n+2)=0;
            SB11(n+2)=0;
            SB12(n+2)=0;
            RTZ7(n)=1;

        else

            RTZ7(n)=0;

        end

        if RTZ7(n)==1 && RTZ7B(n-1)==0;

            TB10(n+2)=1;
            TB11(n+2)=1;
            TB12(n+2)=1;

        end

        if RTZ7(n)==1

           RTZ7B(n)=1;
```

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```
else

    RTZ7B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone8 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_8_RC(n)==1 && Z8RCB(n-1)==0

    disp('Attempting Zone 8 Reclose');

    CB12(n+1)=1;
    CB13(n+1)=1;

end

if CB12(n)==1 || CB13(n)==1

    SB12(n)=1;
    SB13(n)=1;

end

if Z8RC(n)==1

   Z8RCB(n)=1;

else

    Z8RCB(n)=0;

end

if Zone_8_RC(n)==1 && Z8RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 8 Locked Out');

    SB12(n+2)=0;
    SB13(n+2)=0;
    RTZ8(n)=1;

else

    RTZ8(n)=0;

end

if RTZ8(n)==1 && RTZ8B(n-1)==0;

    TB12(n+2)=1;
    TB13(n+2)=1;
```

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```
end

if RTZ8(n)==1

   RTZ8B(n)=1;

else

    RTZ8B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone9 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_9_RC(n)==1 && Z9RCB(n-1)==0

    disp('Attempting Zone 9 Reclose');

    CB13(n+1)=1;
    CB14(n+1)=1;
    CB15(n+1)=1;


end

if CB13(n)==1 || CB14(n)==1 || CB15(n)==1

    SB13(n)=1;
    SB14(n)=1;
    SB15(n)=1;

end

if Z9RC(n)==1

   Z9RCB(n)=1;

else

    Z9RCB(n)=0;

end

if Zone_9_RC(n)==1 && Z9RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 9 Locked Out');

    SB13(n+2)=0;
    SB14(n+2)=0;
    SB15(n+2)=0;
    RTZ9(n)=1;
```

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```
else

    RTZ9(n)=0;

end

if RTZ9(n)==1 && RTZ9B(n-1)==0;

    TB13(n+2)=1;
    TB14(n+2)=1;
    TB15(n+2)=1;

end

if RTZ9(n)==1

   RTZ9B(n)=1;

else

    RTZ9B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone10 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_10_RC(n)==1 && Z10RCB(n-1)==0

    disp('Attempting Zone 10 Reclose');

    CB15(n+1)=1;
    CB16(n+1)=1;
    CB17(n+1)=1;


end

if CB15(n)==1 || CB16(n)==1 || CB17(n)==1

    SB15(n)=1;
    SB16(n)=1;
    SB17(n)=1;

end

if Z10RC(n)==1

   Z10RCB(n)=1;

else

    Z10RCB(n)=0;
```

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```
end

if Zone_10_RC(n)==1 && Z10RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 10 Locked Out');

    SB15(n+2)=0;
    SB16(n+2)=0;
    SB17(n+2)=0;
    RTZ10(n)=1;

else

    RTZ10(n)=0;

end

if RTZ10(n)==1 && RTZ10B(n-1)==0;

    TB15(n+2)=1;
    TB16(n+2)=1;
    TB17(n+2)=1;

end

if RTZ10(n)==1

   RTZ10B(n)=1;

else

    RTZ10B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone11 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_11_RC(n)==1 && Z11RCB(n-1)==0

    disp('Attempting Zone 11 Reclose');

    CB15(n+1)=1;
    CB16(n+1)=1;
    CB17(n+1)=1;


end

if CB15(n)==1 || CB16(n)==1 || CB17(n)==1

    SB15(n)=1;
```

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```
    SB16(n)=1;
    SB17(n)=1;

end

if Z11RC(n)==1

   Z11RCB(n)=1;

else

    Z11RCB(n)=0;

end

if Zone_11_RC(n)==1 && Z11RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 11 Locked Out');

    SB15(n+2)=0;
    SB16(n+2)=0;
    SB17(n+2)=0;
    RTZ11(n)=1;

else

    RTZ11(n)=0;

end

if RTZ11(n)==1 && RTZ11B(n-1)==0;

    TB15(n+2)=1;
    TB16(n+2)=1;
    TB17(n+2)=1;

end

if RTZ11(n)==1

   RTZ11B(n)=1;

else

    RTZ11B(n)=0;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Zone12 RC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Zone_12_RC(n)==1 && Z12RCB(n-1)==0
```

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```
    disp('Attempting Zone 12 Reclose');

    CB19(n+1)=1;
    CB20(n+1)=1;

end

if CB19(n)==1 || CB20(n)==1

    SB19(n)=1;
    SB20(n)=1;

end

if Z12RC(n)==1

   Z12RCB(n)=1;

else

    Z12RCB(n)=0;

end

if Zone_12_RC(n)==1 && Z12RCB(n)==1

    disp('Reclose Failed');
    disp('Zone 12 Locked Out');

    SB19(n+2)=0;
    SB20(n+2)=0;
    RTZ12(n)=1;

else

    RTZ12(n)=0;

end

if RTZ12(n)==1 && RTZ12B(n-1)==0;

    TB19(n+2)=1;
    TB20(n+2)=1;

end

if RTZ12(n)==1

   RTZ12B(n)=1;

else
```

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```
    RTZ12B(n)=0;

end


end


t=1:2000;

for ii=1:20,
    for jj=1:100,
        if SB1(ii) == 0,
            SB1n(jj+100*(ii-1))=0;
        else
            SB1n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if SB2(ii) == 0,
            SB2n(jj+100*(ii-1))=0;
        else
            SB2n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if SB20(ii) == 0,
            SB20n(jj+100*(ii-1))=0;
        else
            SB20n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if TB1(ii) == 0,
            TB1n(jj+100*(ii-1))=0;
        else
            TB1n(jj+100*(ii-1))=1;
```

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```
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if TB2(ii) == 0,
            TB2n(jj+100*(ii-1))=0;
        else
            TB2n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if TB20(ii) == 0,
            TB20n(jj+100*(ii-1))=0;
        else
            TB20n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if TB3(ii) == 0,
            TB3n(jj+100*(ii-1))=0;
        else
            TB3n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if TB4(ii) == 0,
            TB4n(jj+100*(ii-1))=0;
        else
            TB4n(jj+100*(ii-1))=1;
       end

    end
```

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```
end

for ii=1:20,
    for jj=1:100,
        if CB1(ii) == 0,
            CB1n(jj+100*(ii-1))=0;
        else
            CB1n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if CB2(ii) == 0,
            CB2n(jj+100*(ii-1))=0;
        else
            CB2n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if CB20(ii) == 0,
            CB20n(jj+100*(ii-1))=0;
        else
            CB20n(jj+100*(ii-1))=1;
       end

    end

 end

for ii=1:20,
    for jj=1:100,
        if SB3(ii) == 0,
            SB3n(jj+100*(ii-1))=0;
        else
            SB3n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
```

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```
        if SB4(ii) == 0,
            SB4n(jj+100*(ii-1))=0;
        else
            SB4n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if SB5(ii) == 0,
            SB5n(jj+100*(ii-1))=0;
        else
            SB5n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if SB6(ii) == 0,
            SB6n(jj+100*(ii-1))=0;
        else
            SB6n(jj+100*(ii-1))=1;
       end

    end

end

for ii=1:20,
    for jj=1:100,
        if SB7(ii) == 0,
            SB7n(jj+100*(ii-1))=0;
        else
            SB7n(jj+100*(ii-1))=1;
       end

    end

end
```

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```
figure (1)
subplot(3,1,1)
plot(t/100,SB1n,'r')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 1 Status')
axis([0 20 -2 2])

subplot(3,1,2)
plot(t/100,SB2n,'b')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 2 Status')
axis([0 20 -2 2])

subplot(3,1,3)
plot(t/100,SB20n,'g')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 20 Status')
axis([0 20 -2 2])

figure (2)
subplot(3,1,1)
plot(t/100,TB1n,'r')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 1 Trip Signal')
axis([0 20 -2 2])

subplot(3,1,2)
plot(t/100,TB2n,'b')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 2 Trip Signal')
axis([0 20 -2 2])

subplot(3,1,3)
plot(t/100,TB20n,'g')
grid on
```

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```
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 20 Trip Signal')
axis([0 20 -2 2])

figure(3)
subplot(3,1,1)
plot(t/100,CB1n,'r')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 1 Close Signal')
axis([0 20 -2 2])

subplot(3,1,2)
plot(t/100,CB2n,'b')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 2 Close Signal')
axis([0 20 -2 2])

subplot(3,1,3)
plot(t/100,CB20n,'g')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 20 Close Signal')
axis([0 20 -2 2])



Breaker Fail Plot


figure (1)
subplot(3,1,1)
plot(t/100,SB5n,'r')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 5 Status')
axis([0 20 -2 2])

subplot(3,1,2)
plot(t/100,SB6n,'b')
grid on
```

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```
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 6 Status')
axis([0 20 -2 2])

subplot(3,1,3)
plot(t/100,SB7n,'g')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 7 Status')
axis([0 20 -2 2])

figure (2)
subplot(4,1,1)
plot(t/100,SB3n,'r')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 3 Status')
axis([0 20 -2 2])

subplot(4,1,2)
plot(t/100,SB4n,'b')
grid on
hold on
ylabel('1=Closed/0=Open')
xlabel('Time(ms)')
title('Breaker 4 Status')
axis([0 20 -2 2])

subplot(4,1,3)
plot(t/100,TB3n,'b')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 3 Trip Signal')
axis([0 20 -2 2])

subplot(4,1,4)
plot(t/100,TB4n,'b')
grid on
hold on
ylabel('1=On/0=Off')
xlabel('Time(ms)')
title('Breaker 4 Trip Signal')
axis([0 20 -2 2])
```

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